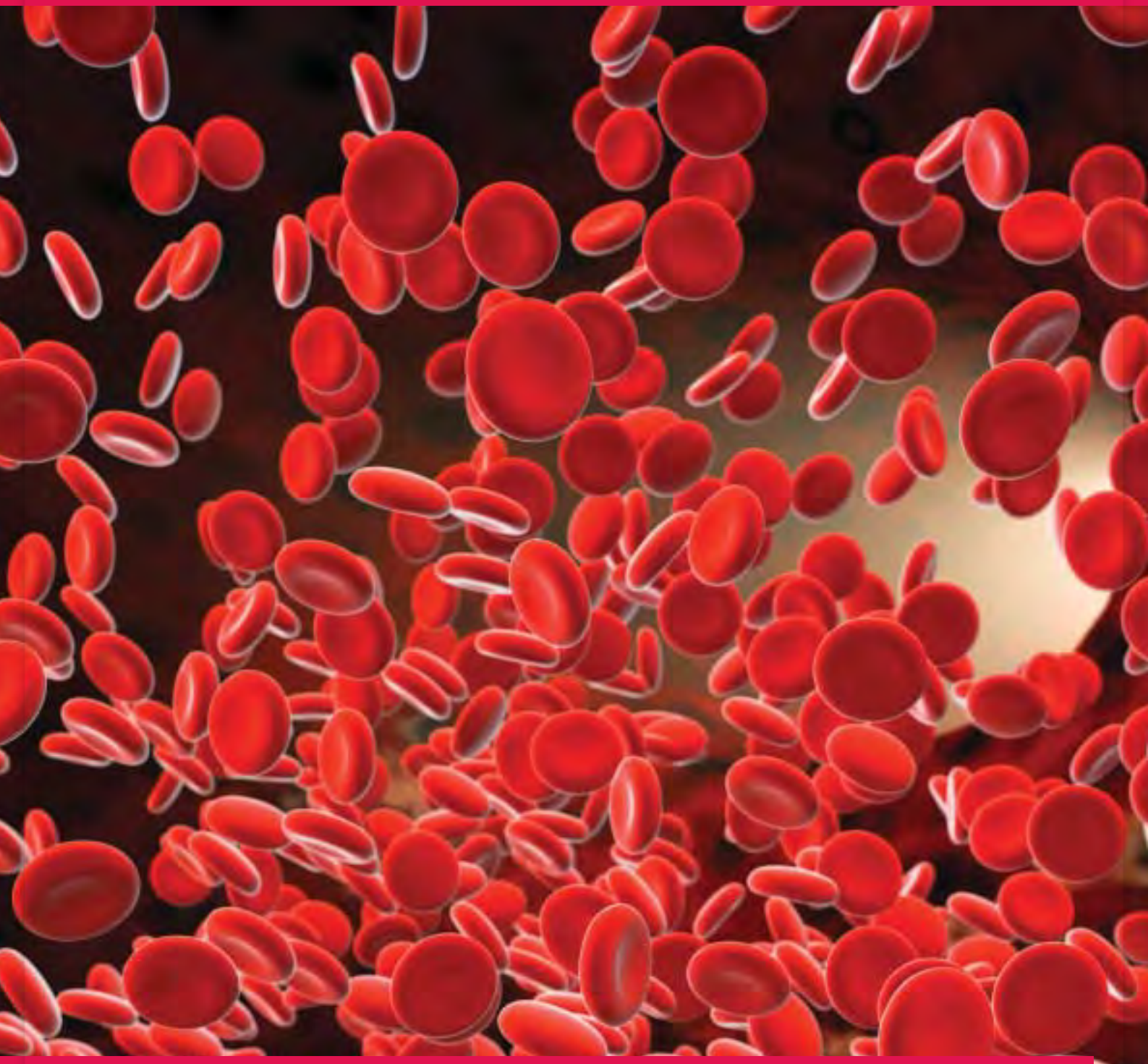
Cambridge Pre-U Syllabus

Cambridge International Level 3 Pre-U Certificate in **BIOLOGY**

For examination in 2013, 2014 and 2015



UNIVERSITY of CAMBRIDGE
International Examinations

Cambridge Pre-U

Biology (9790)

Cambridge International Level 3
Pre-U Certificate in Biology (Principal)

For examination in 2013, 2014 and 2015

QN 500/3807/2

Support

CIE provides comprehensive support for all its qualifications, including the Cambridge Pre-U. There are resources for teachers and candidates written by experts. CIE also endorses a range of materials from other publishers to give a choice of approach. More information on what is available for this particular syllabus can be found at **www.cie.org.uk**.

Syllabus updates

This syllabus is for teaching from 2011 and is valid for examination in 2013, 2014 and 2015.

If there are any changes to this syllabus, CIE will write to Centres to inform them. This syllabus will also be published annually on the CIE website (**www.cie.org.uk/cambridgepreu**). The version of the syllabus on the website should always be considered as the definitive version.

Further copies of this, or any other Cambridge Pre-U syllabus, can be obtained by either downloading from our website **www.cie.org.uk/cambridgepreu**

or contacting:
Customer Services, University of Cambridge International Examinations,
1 Hills Road, Cambridge CB1 2EU
Telephone: +44 (0)1223 553554
Fax: +44 (0)1223 553558
E-mail: **international@cie.org.uk**

Cambridge International Level 3 Pre-U Certificate

Biology

9790

Contents

Introduction

Cambridge Pre-U syllabuses aim to equip candidates with the skills required to make a success of their subsequent studies at university, involving not only a solid grounding in each specialist subject at an appropriate level, but also the ability to undertake independent and self-directed learning and to think laterally, critically and creatively. The Cambridge Pre-U curriculum is underpinned by a core set of educational principles:

- A programme of study which supports the development of well-informed, open and independent-minded individuals capable of applying their skills to meet the demands of the world as they will find it and over which they may have influence.
- A curriculum which retains the integrity of subject specialisms and which can be efficiently, effectively and reliably assessed, graded and reported to meet the needs of universities.
- A curriculum which is designed to recognise a wide range of individual talents, interests and abilities and which provides the depth and rigour required for a university degree course.
- A curriculum which encourages the acquisition of specific skills and abilities, in particular the skills of problem solving, creativity, critical thinking, team working and effective communication.
- The encouragement of 'deep understanding' in learning – where that deep understanding is likely to involve higher order cognitive activities.
- The development of a perspective which equips young people to understand a range of different cultures and ideas and to respond successfully to the opportunity for international mobility.

Cambridge Pre-U Principal Subject syllabuses are linear. A candidate taking a Principal Subject must take all the components together at the end of the course in one examination session.

Reflecting the constantly advancing state of scientific knowledge, Cambridge Pre-U science syllabuses have been designed to allow incorporation of cutting-edge science. Candidates will be able to bring with them, and build on, the knowledge and understanding gained in their 16+ science courses.

Cambridge Pre-U science syllabuses aim to develop and nurture in candidates a philosophy of evidence-based thinking and instil in them a notion of inquisitiveness and intellectual enjoyment in exploring a topic further on their own. The assessments foster practical approaches to problem-solving and engender an appreciation of the need for accuracy and precision when working with data.

The syllabuses are also designed to develop candidates' ability to communicate their understanding to a range of audiences, both orally and in written form; to encourage the articulation of informed opinions about science and technology issues, particularly controversial ones, and to enable them to participate in debate about such issues.

The Cambridge Pre-U science suite should invoke in candidates an enthusiasm for science, and encourage reflection on the nature, history and philosophy of scientific enquiry.

The Cambridge Pre-U biology syllabus:

- Offers a solid grounding in the fundamental principles of biology that will be useful for further study at university.
- Encourages independent study and research, collaborative working and the skills of analysis and synthesis, which are useful in all university courses.
- Offers teachers and students opportunities to take content or context approaches to the subject matter.
- Allows flexibility of delivery for a variety of learning styles.
- Concentrates on the development of many skills associated with studying biological sciences at a higher level.
- Offers many opportunities to make links between different topics that may not be possible in modular courses.

Biology is a subject with a solid foundation based on many decades of research and yet is in the exciting position of having developed at a faster rate in the last 20 years than at any time in its history. While most of the Cambridge Pre-U biology specification is familiar material – molecular biology, biochemistry, cell biology, physiology, histology, genetics and environmental biology – it is distinctive in its approach to the emerging fields of molecular genetics (section 1.6), biotechnology (section 1.7) and immunology (section 3.5).

The course has been constructed with the young bioscientist in mind. It fits broadly into four underlying themes, which are reflected in the main sections:

- Cell biology (Section 1)
- Evolution and the fundamentals of life (Section 2)
- Whole organism biology (Section 3 and Section 4)
- Environmental biology (Section 5)

Each of these could be used as a framework on which to base a teaching scheme of work, as could the theme of information processing and transfer.

This provides the opportunity to promote an experience that is exciting for both the learner and the teacher, and is thus innovative, stimulating and motivational. It is expected that a course developed from this syllabus will engender curiosity about and interest in organisms of all kinds.

Prior knowledge and progression

The syllabus builds on the candidate's understanding of science whether this has been gained from Level 2 (IGCSE, GCSE, Cambridge International Certificate) qualifications in Biology, IGCSE Co-ordinated Science, GCSE Science plus GCSE Additional Science or other comparable qualifications. It is recommended that candidates have attained communication and literacy skills at a level equivalent to IGCSE and GCSE Grade C in English.

The course will equip candidates with a coherent theoretical and practical base of transferable skills and key knowledge suitable for future study and employment in biology and related fields (e.g. medicine, biochemistry, applied sciences) whilst providing thought-provoking material to appeal to those who do not wish to pursue a scientific career.

Aims

The course aims to:

- Allow teachers and candidates some autonomy and flexibility in the delivery mode for this syllabus.
- Stimulate and motivate the learner to take responsibility for their learning by pursuing topics beyond the syllabus; progressing towards a broad and deep knowledge and understanding of biology.
- Provide opportunities for candidates to learn and analyse independently.
- Instil in candidates safe laboratory practices and equip them with the necessary laboratory skills to pursue the subject further.
- Develop transferable skills.
- Promote an awareness of the use and development of scientific models.
- Stimulate a caring interest in the environment: encompassing the environmental impact of human activities including bioscience and its applications.
- Show the importance of biology in our own lives and in society.
- Present biology as a cooperative and cumulative activity, subject to cultural, technological, economic, social and ethical limitations.
- Develop an understanding of the links between biology, chemistry, physics and other areas.
- Develop attitudes relevant to science such as: initiative; inventiveness; objectivity; integrity; the skills of enquiry; concern for accuracy and precision.
- Provide the tools for candidates to: develop an informed interest in scientific issues; become confident citizens in a technological world; participate in public debate on socio-scientific issues.

Scheme of assessment

For the Principal Pre-U qualification in biology, candidates take all three components together at the end of the course in the same session.

Component	Component name	Duration	Weighting (%)	Type of assessment
1	Structured	2½ hours	40	Written paper, externally set and marked
2	Long answer	2¾ hours	45	Written paper, externally set and marked
3	Practical	2½ hours	15	Practical exam, externally set and marked

Assessment objectives

AO1	**Knowledge with understanding** Candidates will be expected to demonstrate knowledge and understanding in relation to: • principles, concepts and theories • biological relationships and the models used to explain them • the vocabulary, terminology, conventions and definitions used • laboratory apparatus and methods and their use • the development of biology through the scientific method in which theories are based on observation, experimental results, and deductions • the cultural and historical influences on developments in biology • scientific and technological applications • the social, ethical, economic and environmental implications of the study and application of biology The curriculum content of the syllabus defines the factual knowledge that candidates may be required to recall and explain.
AO2	**Analysis and application** Candidates will be expected to: • select, organise, interpret and analyse information in familiar and unfamiliar contexts • identify, describe and explain patterns, trends and relationships • make comparisons that may include the identification of similarities and differences and advantages and disadvantages • make inferences and conclusions and construct arguments • assess the validity of information and conclusions • use skills, knowledge and understanding from different areas of study to solve problems in familiar and unfamiliar situations • communicate information clearly, logically and concisely using appropriate specialist vocabulary This assessment objective relates to information which may not be listed in the curriculum content of the syllabus. Information includes visual, textual and numerical stimulus material. In answering questions, candidates will be expected to use principles and concepts from within the syllabus and apply them in a logical, reasoned or deductive manner to a new situation.
AO3	**Experimental and investigative skills** Candidates will be expected to: • construct hypotheses and use them to make predictions • plan investigations which may include testing a hypothesis • know how to use apparatus and techniques skilfully, safely and effectively • make and record observations methodically and with due regard for precision, accuracy and repeatability • manipulate, present and analyse raw data • evaluate data, methods and techniques, identify limitations and suggest improvements

The assessment objectives and assessment model in this syllabus have been designed to allow appropriate progression from GCSE, IGCSE, and other qualifications of similar level. This syllabus includes little that should already have been covered. Learners are expected to revisit areas already covered in previous courses, rather than having these re-taught, taking responsibility for their own learning and progress; an important skill.

Key features of the assessment of this biology syllabus include:

- Scope for incorporating cutting-edge science into the framework of this syllabus.
- An exciting assessment framework featuring:
  - examination questions targeted at the full range of ability, some set in familiar and some in novel contexts
  - a variety of assessment methods including objective, short answer and essay questions and a practical paper
  - a practical examination to reward candidates who have gained a wide range of laboratory and higher-order practical skills

The course gives candidates opportunities to develop their interests and communication skills through: researching topics and communicating their findings in presentations, discussions, critical essays; designing learning aids and making posters, flow diagrams and charts. The course develops experimental competence by suggesting appropriate practical work in each section and by giving an accessible and rigorous summative test of practical skills in the practical examination and in the planning question in Paper 2.

The practical examination is designed to reward effective learning of practical skills. It provides a formal assessment model that will encourage the teaching and learning of practical skills as an integrated part of the course. It will make a virtue of the 'plan, obtain data, analyse and evaluate' model as well as giving a clear incentive to the development of skills of making and presenting observations.

Relationship between scheme of assessment and assessment objectives

The table gives the approximate number of marks allocated to each assessment objective in each paper and the percentage of marks allocated to each assessment objective across the whole assessment.

	Paper 1 max. 100 (marks)	Paper 2 max. 120 (marks)	Paper 3 max. 80 (marks)	Whole Assessment (%)
AO1: Knowledge with understanding	55	48	0	40
AO2: Analysis and application	45	58	27	45
AO3: Experimental and practical skills	0	14	53	15

Description of components

Contexts for questions on written papers

Questions on the written papers will, where possible, be set in novel contexts featuring various applications of biology, some of which will be unfamiliar. Medicine, veterinary science, pharmacology, crop and livestock production, conservation, forensics, genomics and proteomics are some of the areas that may provide contexts for questions. Some questions may be set in the context of recent research. Historical and ethical scenarios will also be used. Familiar practicals from within the syllabus and unfamiliar practicals will be used as contexts for questions that candidates are expected to answer based on the practical skills that they have developed.

Component 1: Structured

Written Paper, 100 marks, 2½ hours.
All questions are compulsory and will be based on the whole of the syllabus content.
This paper will consist of two sections:

- **Section A** (20 marks). This will consist of 20 objective questions. These may be multiple-choice questions of various kinds, where candidates choose one of four or more given statements which could be correct, or structured questions which require a single word answer.
- **Section B** (80 marks). This will consist of a number of compulsory structured short-answer questions.

Component 2: Long-Answer

Written Paper, 120 marks, 2¾ hours
This paper will consist of three sections:

- **Section A: Data Analysis and Planning Task** (60 marks). This section will include tasks to assess the higher-order skills of planning, analysing, making conclusions and evaluating. The section will have a variable number of questions, which will require candidates to solve problems. Questions may ask them to interpret data given in a table, chart or graph. Candidates may be expected to plot, measure and interpret graphs. The Planning Task will involve candidates writing a highly structured plan drawing on the practical skills they have developed during their course. Candidates will be advised to spend no more than 65 minutes on Section A.
- **Section B: Case Study** (30 marks). There will be several structured questions relating to a passage which may be taken or adapted from a source such as a scientific journal or book and which will not necessarily relate directly to the content of the syllabus. Questions may ask candidates to explain the meaning of terms used in the passage, rephrase parts of the passage, analyse data in the passage, perform calculations and draw conclusions from what they have read. Candidates will be advised to spend no more than 50 minutes on this section.
- **Section C: Synoptic Analysis and Argumentation** (30 marks). This section, which may include textual or other stimulus material, will consist of a choice of one from a selection of three unstructured questions requiring responses in the form of a discursive essay. Quality of written communication will be given a percentage of the marks available. Candidates should use clear English and will be expected to produce well-structured arguments. Questions in this section may be set on any area of the syllabus, and candidates may wish to use material from many areas of the syllabus within a single answer. Within the Curriculum Content Learning Outcomes, the command word *discuss* indicates topic areas particularly suited to this kind of questioning, where there is an almost infinite variety of potential responses. Candidates will be advised to spend no more than 50 minutes on this section.

Component 3: Practical

Laboratory based Practical Examination, 80 marks 2½ hours
This paper will consist of two sections:

- **Section A** (45 marks). This will consist of one or two practical-based questions.
- **Section B** (35 marks). This will consist of one or more short questions involving the use of a microscope and its related skills. In addition, candidates may be provided with secondary data to analyse and interpret.

The syllabus makes very clear the skills that are to be developed by the candidates during the course, and thus the skills that will be tested during the examination. The examination will be set on the practical learning outcomes that are listed at the end of each section of the syllabus. Candidates will be expected to have considerable experience of practical work in order to be able to succeed in the tasks set. The examination will not be of the open-book type and there will not be any pre-release materials for candidates. There will be Confidential Instructions for Centres which will facilitate the setting up of the examination in an appropriate way. The practical set up will not be onerous even for large Centres that have been running appropriate Pre-U Biology practical work during the course.

Centres can divide their candidates into two sessions to facilitate laboratory management if they wish. Centres may choose to divide up their candidates into more groups if required provided that CIE regulations on the running and security of practical examinations are maintained.

Curriculum content

The syllabus is divided into five sections, as follows:

Section 1 The cell
- **1.1 Eukaryotic cell structure**
- **1.2 Prokaryotic cells**
- **1.3 Cell replication**
- **1.4 Enzymes**
- **1.5 Respiration**
- **1.6 Genes and protein synthesis**
- **1.7 Applications of cell biology**

Section 2 The origin and evolution of life
- **2.1 The origins of life**
- **2.2 The chemicals of life**
- **2.3 The evolution of life**
- **2.4 Classification**

Section 3 Animal physiology
- **3.1 Transport systems**
- **3.2 Nutrition**
- **3.3 Nerves, muscles and behaviour**
- **3.4 Homeostasis and cell signalling**
- **3.5 The immune system**
- **3.6 Reproduction**

Section 4 The life of plants
- **4.1 Transport in plants**
- **4.2 Photosynthesis**
- **4.3 Reproduction**
- **4.4 Control of plant processes**

Section 5 Environmental studies
- **5.1 Adaptation**
- **5.2 Measuring and conserving biodiversity**

Cambridge Pre-U biology places considerable emphasis on the understanding and use of scientific ideas and principles in a variety of situations, including those which are new to candidates. As described in the Aims, it is expected that programmes of study based on this syllabus will feature a variety of teacher-centred and student-centred learning experiences designed to enhance the development of skills and comprehension. It will also prepare candidates for an assessment that will, within less familiar contexts, test expertise, understanding and insight. A scheme of work should be produced by teachers to reflect the sequence and repertoire of learning opportunities that they feel are most appropriate for their candidates.

Teachers should take note of the greater than 50% weighting for skills (including handling information, solving problems, practical, experimental and investigative skills) compared to less than 50% for knowledge and understanding. Teachers' schemes of work, and the sequence of learning activities, should reflect this balance, so that the aims of the syllabus may be met, and the candidates prepared for the assessment.

It is expected that every student, regardless of ability, will cover the content as described and will thus be able to approach the examination with confidence and that they will find it accessible to a level that reflects their ability and current developmental status as a biologist. It is likely that the higher achievers will have read around, investigated, discussed and thought about a wide range of additional material.

In each section of the syllabus it is anticipated that candidates will use the content for broad-ranging discussion and argumentation. It is expected that candidates will carry out their own research and will bring their own interests to bear on particular topics to the benefit of the whole group. This will prepare all the candidates for the more discursive aspects of the course and will prepare them well for study at university.

Similarly, candidates may wish to extend their study of the practical work by carrying out other research activities that may or may not involve further practical work.

In the context of the curriculum content learning outcomes of this syllabus, the following terms will be met and are intended to have meanings as shown in the table below.

Term	Intended meaning
Limited to …	The list of examples or level of detail given in the syllabus is considered to be sufficient at this level, so that inclusion of further examples or more detail is unlikely to be of benefit to candidates. Question setters will assume that all candidates have studied the topic to the specified level of detail and included the specified examples.
Including … and e.g. …	For some individual candidates and cohorts, sufficient examples or details are given to form a coherent understanding without any further exemplification or detail. For other individual candidates or cohorts, there may usefully be the opportunity to pursue the topic to a greater depth. Great care should be taken not to overload the course with content beyond the level that is intended, so that not every opportunity to include more material should be taken. Question setters will assume that all candidates have studied the topic to the specified level of detail and included the specified examples.
… With emphasis on …	This is an indication that the particular aspects of the topic so described should be the focus of most of the teaching and learning effort, and other aspects should form a smaller part, for example in cell division, where the features of chromosome behaviour that contribute to various outcomes should be studied in more detail than other aspects such as the changes to centrioles and nuclear membrane.
Command words such as state, outline, describe, explain, suggest, compare and discuss …	A glossary is given at the end of the syllabus that lays out the intended meanings of these terms in the context of the assessment. This glossary will also be of considerable use in helping teachers and candidates determine the intended depth of study of the course.
Use…	The term use in the syllabus learning outcomes points out particular places where candidates will need to apply their understanding of aspects of biology to the solving of problems, for example in genetics.
Details of … are not required	This is an area where it is considered that inclusion of the material specifically excluded from the syllabus is unlikely to be of benefit to candidates and might prejudice their progress in other areas that are essential to study at this level. Question setters will assume that no candidates have studied the material specifically excluded.

1. The cell

This section looks at life in terms of the cell. Knowledge of eukaryotic and prokaryotic cellular structure and the processes which take place in all living cells is fundamental to explaining how life 'works'. Cell biology also has medical and commercial applications and these are also considered in this section.

These questions may be put to candidates to stimulate discussion and prompt and direct their own researches while covering Section 1.

- What makes eukaryotes different from prokaryotes?
- Are eukaryotes more successful than prokaryotes?
- What are the advantages and disadvantages of using electron microscopes?
- How can I determine what is inside a cell and what the parts do?
- How are intracellular structures adapted to their functions?
- How do cells replicate?
- How are meiosis and genetics connected?
- How and why do a variety of proteins catalyse such a variety of different reactions so specifically?
- If enzymes denature at 55°C, how do organisms live in hydrothermal vents deep in the ocean or in hot springs at 95°C?
- What is it about ATP that makes it so important?
- How does ATP get made?
- Why is anaerobic respiration so much less efficient at releasing energy from a glucose molecule than aerobic respiration?
- What is the role of DNA?
- How do organisms control their genes?
- What is genetic engineering and is it a good thing or a bad thing?
- How is knowledge and understanding of biology applied to gene technology?
- Selective breeding ... is it genetic engineering or not?
- How do I transfer a gene from one species to another, and how can I tell if I have done it successfully?

1.1 Eukaryotic cell structure

Content

Microscopy

Cell membranes

Organelles: structure and function

Learning outcomes

Candidates should be able to:

(a) explain the relative advantages of light and electron microscopes (including the theoretical basis for these relative advantages)

(b) explain and distinguish between resolution and magnification with reference to light microscopy and electron microscopy

(c) discuss the importance of cell surface membranes in defining cells, as a characteristic of all living things and the extent to which they appear to be essential for life

(d) describe and explain the fluid mosaic model

(e) discuss the roles of membrane proteins including transporters (channels and carriers [including CFTR]), pumps, receptors and antigens

(f) describe the factors affecting the permeability and fluidity of membranes

(g) explain how and why different substances move across membranes (including simple and facilitated diffusion, osmosis, active transport, endocytosis (phagocytosis and pinocytosis), exocytosis, (secretory pathway)

(h) recognise the following cell organelles and describe their functions

- nucleus
- nuclear envelope
- nucleolus
- rough and smooth endoplasmic reticulum
- ribosomes
- Golgi apparatus
- lysosomes
- secretory vesicles
- proteasomes
- mitochondria
- chloroplasts
- vacuoles
- cell walls
- centrioles
- cilia and flagella

Practical learning outcomes

Candidates should be able to:

(i) use a light microscope, stage micrometer scale and eyepiece graticule

(ii) correctly measure, using a light microscope and specimens, the size of objects and calculate their magnification

(iii) produce drawings of an organism, a section through a small organism and a part of an organism as seen under the light microscope

(iv) produce correctly labelled and annotated drawings of cells from microscopic examination and from electronmicrographs

(v) recognise organelles in a variety of cells from across the four eukaryotic kingdoms

(vi) investigate the movement of materials through cell membranes, for example by diffusion, osmosis and active transport

(vii) estimate the water potential of a plant tissue by investigating the change in length or mass of suitable plant tissue

(viii) estimate the solute potential of plant cells using percentage plasmolysis of suitable plant epidermal cells

(ix) investigate the effect of temperature and different solvents on the permeability of membranes

(x) investigate endocytosis and intracellular digestion in a protoctist, such as *Paramecium* or *Vorticella*, or using yeast stained with neutral red

1.2 Prokaryotic cells

Content

Structure of prokaryotic cells

Pathogenic bacteria

Antibiotics

Reproduction

Learning outcomes

Candidates should be able to:

(a) outline key structural features of prokaryotic cells (including: unicellular, 1–5 μm diameter, peptidoglycan cell walls, lack of membrane-bound organelles, naked circular DNA, 70S ribosomes)

(b) outline the structure and functions of bacterial ribosomes and cell walls and the significance of the structure of bacterial cell walls for the use of antibiotics

(c) explain the mode of transmission and infection of bacterial pathogens (including *Agrobacterium tumefaciens* (Rhizobium radiobacter), *Clostridium tetani*, *Mycobacterium tuberculosis* and *Helicobacter pylori*)

(d) explain the mode of action of penicillin on bacteria (as an example of an antibiotic) and explain why penicillin does not affect viruses

(e) outline the mechanism of asexual reproduction by binary fission in a typical prokaryote

Practical learning outcomes

Candidates should be able to:

(i) investigate Gram staining of bacterial cell walls

(ii) investigate the effect of penicillin or other antibiotics on bacterial growth (e.g. by use of Mast Rings)

1.3 Cell replication

Content

DNA replication

Mitosis

Meiosis

Learning outcomes

Candidates should be able to:

(a) outline the semi-conservative replication of DNA

(b) describe the contribution of Meselson and Stahl in revealing, from various hypotheses, which model correctly describes DNA replication

(c) outline the cell cycle including growth, DNA replication, mitosis and cytokinesis

(d) describe and explain mitosis, with the aid of diagrams, in terms of chromosome, nuclear envelope and centriole behaviour with emphasis on the features of chromosome behaviour that contribute to the production of cells that are genetically identical to each other and to their predecessor

(e) describe how mitosis is controlled by the interaction of extracellular growth factors that control genes which produce intracellular kinase proteins

(f) describe how telomere shortening determines the number of divisions of a cell by mitosis and the role of telomerase reverse transcriptase to reverse the telomere shrinkage in cells that must repeatedly divide throughout life (e.g. cells in the basal layer of skin, stem cells and some white blood cells)

(g) describe meiosis, with the aid of diagrams, in terms of chromosome, nuclear envelope and (where present) centriole behaviour with emphasis on the features of chromosome behaviour that contribute to reductional division

(h) explain how independent assortment and crossing over can contribute to genetic variation (details of stages within prophase 1 are not required)

Practical learning outcomes

Candidates should be able to:

(i) sequence images of eukaryotic cells undergoing mitosis

(ii) prepare and view slides of root tip squashes or other material showing mitosis

(iii) investigate meiosis using prepared slides and photomicrographs of plant or animal tissues

1.4 Enzymes

Content

Structure and function of enzymes

Enzyme kinetics

Commercial uses of enzymes

Learning outcomes

Candidates should be able to:

(a) explain why enzymes are essential to life

(b) describe the structure and properties of enzymes (to include their role as catalysts in catabolic and anabolic reactions [both intracellular and extracellular] and the roles of intracellular kinase enzymes)

(c) explain the specificity of enzymes and the induced-fit mode of action

(d) describe, explain and investigate factors affecting enzyme kinetics including the effect of temperature, pH, substrate and enzyme concentration in terms of activation energy, kinetic energy, successful collisions, complementary shape and fit, as well as active site/substrate interactions including V_{max}

(e) describe end product inhibition and allosteric regulation (including phosphofructokinase and ATP)

(f) explain the impact of deficiency of phenylalanine hydroxylase (PAH) in phenylketonuria (PKU) as an example of an inherited error of metabolism

(g) describe and explain the effect of competitive and non-competitive inhibitors on enzyme activity

(h) outline the use of reverse transcriptase inhibitors and protease inhibitors for treatment of HIV infection

(i) explain the advantages of enzyme immobilisation

(j) explain the commercial applications of enzymes including the use of pectinase in the drinks industry

(k) explain the principles of operation of dip sticks containing glucose oxidase enzymes, and biosensors that can be used for quantitative measurement of glucose

Practical learning outcomes

Candidates should be able to:

(i) carry out investigations into the properties of a variety of enzymes in relation to the effect of temperature, pH, inhibitors and concentrations of enzyme and substrate

(ii) investigate the effect of immobilisation of enzymes on re-use of enzymes, ease of removal of enzyme from product and thermostability of enzymes

(iii) investigate the effect of pectinase on the clarification of fruit juices

1.5 Respiration

Content

ATP

Chemiosmosis

Glycolysis

Anaerobic respiration

Reactions within mitochondria

Learning outcomes

Candidates should be able to:

(a) explain the need to release energy to drive metabolic reactions and the role of ATP

(b) outline chemiosmosis as a system in prokaryotes and eukaryotes in which:

- electrons may gain energy from oxidation of chemical substrates and that this energy may be used to do work
- energetic electrons pass through the electron transport system to release energy
- the released energy is used to transfer protons out through membranes
- as these protons diffuse back through the membrane, their kinetic energy is used in membrane-associated ATP synthase to add phosphate to ADP, forming ATP

(c) outline glycolysis (phosphorylation to fructose 1,6-bisphosphate, hydrolysis to triose phosphate, oxidation and dephosphorylation to pyruvate)

(d) outline the link reaction and Krebs cycle within the mitochondrion, general principles of dehydrogenation and decarboxylation to produce ATP, and reduced NAD and FAD

(e) outline anaerobic respiration in animals limited to the oxidation of reduced NAD to regenerate NAD and conversion of pyruvate to lactate and at the same level of detail, compare and contrast this with anaerobic respiration in yeast and plants

(f) compare and contrast the energy released per molecule of glucose substrate in aerobic and anaerobic conditions and explain the reasons for the difference

Practical learning outcomes

Candidates should be able to:

(i) investigate the rate of glucose respiration by yeast in aerobic and anaerobic conditions

(ii) investigate the effect of temperature on the rate of respiration using simple respirometers

1.6 Genes and protein synthesis

Content

The gene and genetic code

Protein synthesis

Control of gene expression

Inheritance and Mendelian genetics

Mutations

Genetic conditions

Learning outcomes

Candidates should be able to:

(a) define a gene as a unit of inheritance or as an ordered sequence of nucleotides located at a particular locus on a particular chromosome which codes for a particular protein, or in certain cases a functional or structural RNA molecule. Discuss the limitations of the latter definition with reference to introns, exons and promoters

(b) describe the genetic code and discuss the extent to which it is true that the code is universal to all organisms

(c) explain protein synthesis in terms of transcription and translation including the roles of DNA, mRNA, tRNA and ribosomes

(d) describe, in outline, eukaryotic introns, exons and the splicing of mRNA

(e) define the term proteomics and outline its importance to biomedicine (limited to diagnosis and drug design)

(f) describe, in outline, the control of gene expression (limited to the *lac* operon in prokaryotes)

(g) state, with examples, the differences between continuous and discontinuous variation (limited to relative number of genes and alleles involved and relative impact of the environment as well as relative range of phenotypes)

(h) define and use the terms allele, locus, phenotype, genotype, dominant, recessive and codominant

(i) use genetic diagrams to solve dihybrid crosses, including those involving sex linkage, autosomal linkage, epistasis, codominance and multiple alleles

(j) use and interpret the chi-squared test to test the significance of the difference between observed and expected results. (The formula for the chi-squared test will be provided.)

(k) explain that the effects of ionising radiation on living cells can have a range of outcomes including DNA damage which is repaired, DNA damage that cannot be repaired, leading to apoptosis, and DNA damage causing mutations. Mutations that do not kill the cell but are passed on to its descendants during cell division (including mutations that can cause cancer, e.g. those that cause proto-oncogenes to become oncogenes and those that reduce the activity of tumour-suppressor genes)

(l) describe gene mutations, limited to substitution, deletion and insertion

(m) explain, with reference to sickle cell anaemia, cystic fibrosis and hereditary haemochromatosis, how gene mutations might affect expression of a protein and thus affect phenotype (issues related to genetic conditions need to be handled with sensitivity)

(n) describe the causes and outline the symptoms of hereditary haemochromatosis (HH) as an example of a recessive genetic condition (reference should be made to HFE protein)

Practical learning outcomes

Candidates should be able to:

(i) investigate genetics using locally available materials (e.g. locally available plants), germinating seedlings (e.g. rapid-cycling *Brassica*), *Drosophila*, fungi (such as *Sordaria fimicola*), genetic tomatoes, prepared materials such as 'genetic corn-cobs' and any other materials that yield suitable numerical information

(ii) investigate continuous and discontinuous variation with any available materials (e.g. people, plants with suitable single-gene and polygenic characteristics, polymorphic snails, etc.)

1.7 Applications of cell biology

Content

Principles of genetic engineering

Isolating genes

Cloning DNA

Vectors and insertion into host cells

Identifying and cloning transformed cells

Gene therapy and genetic profiling (DNA fingerprinting)

Gene sequencing – methods and applications

Stem cells – isolation and uses

Ethical issues surrounding genetic engineering and the use of stem cells

Learning outcomes

Candidates should be able to:

(a) discuss the potential and actual advantages and disadvantages of transferring genetic material by genetic engineering compared to selective breeding

(b) explain why promoters and other control sequences may have to be transferred as well as the desired gene

(c) explain strategies that are available to isolate the desired gene from the genome of the gene-donor including:

- use of mRNA and reverse transcriptase
- use of restriction endonucleases to fragment the genome, and use of electrophoresis and complementary gene probes to identify relevant fragments from the gene

(d) outline the principles of PCR as used to clone and amplify DNA and discuss the source and importance of *Taq* polymerase

(e) explain strategies that are available to insert DNA into host cells including:

- inserting the DNA into a plasmid vector using restriction enzymes and DNA ligase and then inserting the plasmid vector into a host cell
- use of *Agrobacterium tumefaciens* in inserting DNA into dicotyledonous plant cells
- use of microprojectiles in inserting DNA into monocotyledonous plant cells (e.g. in creating Golden Rice™ and Golden Rice 2)

(f) discuss the advantages and disadvantages of ways that have been used to identify transformed cells including antibiotic resistance genes and green fluorescent protein (GFP) genes

(g) outline how genes are inserted into target cells in gene therapy (limited to liposomes and viral vectors)

(h) explain the limitations, both potential and actual, of gene therapy as a treatment for genetic conditions (including cystic fibrosis and severe combined immunodeficiency [SCID])

(i) outline the processes used in genetic profiling (DNA fingerprinting) including the use of restriction endonucleases, amplification, electrophoresis visualisation (e.g. by fluorescently tagged primers), and match tables

(j) describe methods of DNA sequencing (limited to the chain termination and the dye-terminator methods) and describe uses of this technology (to include the Human Genome Project and uses in taxonomy [molecular phylogenetics] and clinical diagnosis)

(k) describe how stem cells (zygotic, embryonic and adult) are obtained for research

(l) discuss the current and potential uses of stem cells (e.g. replace damaged tissues, study aspects of development and cell chemistry, test new drugs, screen potentially toxic chemicals, facilitate gene therapy)

(m) discuss the ethical implications of the applications of genetic engineering and stem cells, including agricultural, industrial, research and medical applications.

Practical learning outcomes

Candidates should be able to:

(i) investigate aspects of genetic profiling including practical investigation of electrophoresis using dyes and DNA fragments

(ii) investigate transformation of bacteria, e.g. using the pGLO plasmid

(iii) investigate the *lac* operon using ONPG solution

2. The origin and evolution of life

This section deals with the fundamental questions that help us define life – what materials and conditions are required for life to exist, when did it all get started, how are organisms changing and what drives this change?

These questions may be put to candidates to stimulate discussion and prompt and direct their own researches while covering Section 2.

- How and why did life get started?
- Why are some people so sure about the 'historical fact of evolution' and why are other people not so sure?
- Why is water essential for life?
- Where would life be without proteins?
- How independent are mitochondria and chloroplasts?
- What are the mechanisms that drive evolutionary change?
- What is the evidence that evolution explains life in all its richness?
- Why have some organisms become multicellular?
- What exactly defines a species?
- Why is Charles Darwin a controversial figure for some?
- What are the benefits of the classification of organisms?

2.1 The origins of life

Content

Origin of complex organic molecules

Origin of prokaryotic and eukaryotic cells

Advantages of multicellularity

Learning outcomes

Candidates should be able to:

(a) outline the Miller-Urey experiment that showed that complex organic molecules (including amino acids) can form from simple inorganic molecules when subjected to the conditions once thought to have prevailed on Earth four billion years ago when life is thought to have originated

(b) describe the evidence for a single origin of life in terms of conservation of key biochemical mechanisms including the genetic code and the ubiquitin/proteasome mechanism

(c) describe and explain how eukaryotes are thought to have originated about 2.7 billion years ago by endosymbiosis and the evidence that supports the theory of endosymbiosis

(d) discuss the advantages and disadvantages of being multicellular (limited to division of labour and specialisation, greater control of the internal environment, as against, increased complexity and coordination issues, vulnerability to trauma)

Practical learning outcomes

Candidates should be able to:

(i) use a microscope or photomicrographs to compare small multicellular eukaryotes (e.g. *Volvox*, rotifers, tardigrades) with unicellular eukaryotes (e.g. *Amoeba*, *Euglena*, ciliates)

2.2 The chemicals of life

Content

Water

Lipids

Carbohydrates

Proteins

Nucleic acids

Learning outcomes

Candidates should be able to:

(a) describe the chemical and physical properties of water and explain the biological significance of these properties

(b) describe the structures and properties of triglycerides and phospholipids and explain how these are related to their roles in living organisms

(c) describe the formation and breakage of ester bonds such as those found in triglycerides

(d) distinguish between saturated and unsaturated fatty acids

(e) describe the structures and properties of monosaccharides (α- and β-glucose and ribose); disaccharides (maltose and sucrose) and polysaccharides (amylose, amylopectin, cellulose and glycogen) and explain how these are related to their roles in living organisms

(f) describe the formation and breakage of glycosidic bonds

(g) describe the structures and properties of amino acids; globular proteins (including enzymes and haemoglobin) and fibrous proteins (including keratin and collagen) and explain how these are related to their roles in living organisms

(h) describe the formation and breakage of peptide bonds

(i) distinguish between the primary, secondary, tertiary and quaternary structure of proteins

(j) explain the significance of primary, secondary, tertiary and quaternary structure as well as hydrogen, ionic, peptide and disulfide bonding and hydrophobic interactions in giving the shape of 3D globular proteins (tertiary and quaternary structures)

(k) describe the structure of nucleotides to include ATP

(l) describe the condensation of nucleotides to form nucleic acids

(m) describe the structure of DNA and RNA (limited to mRNA and tRNA)

(n) discuss the scientific method with reference to the contributions of Crick, Watson, Wilkins and Franklin in formulating and testing hypotheses in identification of DNA structure

Practical learning outcomes

Candidates should be able to:

(i) investigate some of the key physical and chemical properties of water

(ii) perform biochemical tests to identify types of molecules (including reducing and non-reducing sugars, starch, lipids and proteins) present in a variety of biological materials

(iii) investigate the energy content of carbohydrates, lipids and proteins, using simple calorimetry

2.3 The evolution of life

Content

Selection and changes in allele frequency

Speciation

Aspects of evolution

Learning outcomes

Candidates should be able to:

(a) outline Darwin's and Wallace's observations and conclusions

(b) describe evolutionary patterns of divergence and adaptive radiation including the Galapagos finches as an example

(c) outline the mechanisms leading to evolutionary changes in allele frequency in populations including: the role of mutation in producing genetic variation; how such variations might enable organisms with particular alleles and particular phenotypes to survive better and reproduce more frequently

(d) describe and explain directional, stabilising and disruptive selection

(e) discuss what effect increased environmental stress resulting from global climate change (with increased temperatures and more extreme weather conditions) might have on habitats and organisms and thus on food chains and niche occupation

(f) compare current and background rates of extinction with those during past mass extinctions (students should be aware that these figures are not agreed by all scientists)

(g) explain the role of isolation in allopatric speciation (with particular reference to evidence from 'ring species') and sympatric speciation (in relation to behavioural isolation in African cichlids)

(h) explain the causes and effects of bacterial genetic resistance to antibiotics

Practical learning outcomes

Candidates should be able to:

(i) investigate the relationship between aspects of the environment and features of species such as banded snails (*Cepaea* spp.)

2.4 Classification

Content

The species concept

Classification systems

Learning outcomes

Candidates should be able to:

(a) define the term species with reference to morphological, genetic and biochemical similarities and capability to produce fertile offspring

(b) explain why classification systems are used to categorise organisms

(c) distinguish between phylogenetic (cladistic) and phenetic classification systems and understand the general preference for phylogenetic systems

(d) describe the hierarchy of seven major taxonomic groups from kingdom to species with reference to an example (e.g. *Homo sapiens*)

(e) understand the term binomial nomenclature and why Latin and Greek are used for biological nomenclature

(f) discuss the merits of the five kingdom and the three domain classification systems (limited to utility and phylogenetic validity)

(g) explain the difficulties of including viruses in classifications of organisms

Practical learning outcomes

Candidates should be able to:

(i) recognise key features of the different kingdoms from specimens, photographs and drawings

(ii) use dichotomous keys to identify organisms from different taxa

3. Animal physiology

Section 3 (Animal physiology) and Section 4 (The life of plants) take a look at life in terms of whole organisms.

Animal physiology explores the different ways in which animals feed, reproduce and transport substances around their bodies, highlighted by differences due to adaptation and a constantly changing environment.

These questions may be put to candidates to stimulate discussion and prompt and direct their own researches while covering Section 3.

- Why do large organisms need a transport system?
- How do animals cope with different diets?
- What happens when we age?
- Why do we age?
- How do animals move?
- Why do we need to control internal conditions?
- Why do organ transplants face rejection, but a fetus doesn't?
- To what extent is the placenta a 'life support machine' for a fetus?
- Why sex?

3.1 Transport systems

Content

Structure and function of transport systems in multicellular animals

Ventilation mechanisms

The mammalian circulatory system

Oxygen transport in the blood

Learning outcomes

Candidates should be able to:

(a) discuss the impact of size on surface area/volume ratio and the significance of this for animals

(b) explain the need for mass flow systems in animals

(c) compare ventilation mechanisms and gas exchange in insects, fish and mammals

(d) discuss the advantages and disadvantages of:

- open and closed transport systems
- single and double circulatory systems including the increasing complexity and efficiency of circulatory systems of fish, amphibians and mammals

(e) describe the structures and functions, and explain the relationship between structure and function, of:
- mammalian arteries, veins and capillaries
- cellular components of mammalian blood (including erythrocytes, platelets, lymphocytes, neutrophils, monocytes)
- the mammalian heart – cardiac cycle including pressure changes in the heart, its electrical coordination and its control by the medulla oblongata in the brain

(f) outline the roles of low-density lipoprotein (LDL) and high-density lipoprotein (HDL) in metabolism and transport of lipids and in atherosclerosis

(g) outline the aetiology of coronary heart disease (CHD) as an example of a cardiovascular disease

(h) outline the roles of drugs (limited to warfarin and statins) and surgery (limited to valve replacements, by-pass surgery, transplants and stents) in treatment of cardiovascular disease

(i) explain the functions of blood limited to clotting and the transport of oxygen and carbon dioxide

(j) explain the significance of oxygen haemoglobin dissociation curves and the Bohr effect

Practical learning outcomes

Candidates should be able to:

(i) observe the similarities and differences between mammalian blood cells, restricted to erythrocytes, lymphocytes, neutrophils and monocytes

(ii) investigate the tracheal system of an insect (e.g. locust), the gills of a fish and the trachea and lungs of a mammal

(iii) explain the relationship between structure and function of heart and blood vessels (artery, vein and capillary) using prepared slides (cross reference Section 3.4(iii))

3.2 Nutrition

Content

Modes of nutrition

Mammalian alimentary canal and digestion

Learning outcomes

Candidates should be able to:

(a) compare and contrast the modes of nutrition, dentition and digestive systems of herbivores and carnivores

(b) recall the structure and function of the mammalian alimentary canal including histology of stomach, ileum and pancreas

(c) identify sites of production, activation and action of the following enzymes in humans as an example of a mammal: amylase, maltase; pepsin and trypsin as endopeptidases; exopeptidases; lipase

(d) explain the parts played by bile, mucus and sodium hydrogen carbonate in digestion

Practical learning outcomes

Candidates should be able to:

(i) explain the relationship between structure and function of mammalian stomach, ileum, liver and pancreas (exocrine and endocrine tissues) using histological sections and electronmicrographs

3.3 Nerves, muscles and behaviour

Content

The nervous system

Nerves and synapses

The brain

Muscles

Innate and learned behaviour

Social behaviour in primates

Learning outcomes

Candidates should be able to:

(a) describe the organisation of the central and peripheral nervous systems to include transverse section of the spinal cord

(b) describe the structure and function of sensory and motor neurones

(c) describe the production of the resting potential and the generation and transmission of action potentials in myelinated and unmyelinated neurones

(d) discuss the factors affecting the speed of impulse transmission in neurones (limited to neurone diameter, body temperature and myelination)

(e) describe and explain transmission at chemical synapses including antagonistic excitatory and inhibitory neurotransmitters as exemplified by acetylcholine, noradrenaline and GABA

(f) outline the gross anatomy and functions of the brain (limited to the cerebrum (cerebral hemispheres), thalamus, hypothalamus, midbrain, hind brain (to include the medulla oblongata, pons varolii and cerebellum), the pituitary body, and cerebro-spinal fluid

(g) explain dementia and research into its possible causes, symptoms and treatments including stem cells

(h) describe the structure and functioning of the neuromuscular junction and propagation of the action potential across muscle cells

(i) describe the histology and ultrastructure of striated muscle and relate this to its contraction

(j) describe and explain the sliding filament theory of muscle contraction to include the roles of calcium ions, ATP, actin, myosin, troponin and tropomyosin

(k) explain the advantages of innate and learned behaviours to organisms

(l) describe examples of genetically determined innate behaviours including taxes, kineses, withdrawal reflexes and instinctive behaviours (limited to foraging in *Drosophila*)

(m) describe examples of learned behaviours widespread in the animal kingdom including habituation, imprinting, classical conditioning and operant conditioning

(n) describe examples of social behaviour in primates and discuss the advantages of such behaviour

Practical learning outcomes

Candidates should be able to:

(i) explain the relationship between structure and function of spinal cord, brain (cerebral hemispheres and cerebellum only), nerves, myelinated neurones, synapses, neuromuscular junctions and striated muscle using histological sections and electronmicrographs

(ii) investigate innate behaviour using choice chambers and suitable motile invertebrates

(iii) use simple T mazes to investigate operant conditioning using suitable motile invertebrates

3.4 Homeostasis and cell signalling

Content

Homeostasis

Regulatory hormones

The roles of the liver in homeostasis

The roles of the kidney and hypothalamus in homeostasis

Cell signalling

Learning outcomes

Candidates should be able to:

(a) define homeostasis as the ability to maintain a dynamic equilibrium resulting in a stable internal environment using negative feedback mechanisms

(b) describe the structure and function of the liver to include its role in blood sugar control, deamination, transamination, detoxification and heat generation

(c) explain the actions of insulin and glucagon on the hepatocyte to include the role of membrane receptors and second messengers as well as membrane permeability to glucose

(d) outline the causes, diagnosis, effects and treatment of types 1 and 2 diabetes

(e) describe the gross anatomy and histology of the kidney and explain its role in excretion and osmoregulation with reference to ultrafiltration, selective reabsorption and countercurrent multiplier

(f) describe the role of the hypothalamus, posterior pituitary and ADH in osmoregulation

(g) describe the role of the medulla oblongata in controlling the circulatory system (X ref Section 3.1(e))

(h) outline the principles of cell signalling in terms of:

- ligand-receptor interaction
- signal transduction
- enzyme cascade and amplification
- change in cell functioning

(i) outline the functioning of G-protein receptors in transduction of signals including increased extracellular ADH and glucagon concentrations

Practical learning outcomes

Candidates should be able to:

(i) examine the gross structure of the kidney

(ii) examine the detailed structure of the nephron with associated blood vessels using histological sections and electronmicrographs

(iii) investigate examples of homeostasis, such as control of heart-rate and osmoregulation

3.5 The immune system

Content

Structure, function and physiology of the mammalian immune system

Monoclonal antibodies

Learning outcomes

Candidates should be able to:

(a) contrast the specific and non-specific immune systems

(b) outline the role of B-cells, plasma cells, memory cells, helper-T cells and cytotoxic-T cells in giving specific immune primary and secondary responses

(c) discuss the structure and action of antibodies (including variable and non-variable regions of the monomeric immunoglobin IgG, but not including the range of types and functions of immunoglobins)

(d) distinguish between active and passive immunity, as well as natural and artificial immunity, limited to specific examples including tetanus, TB, polio and measles

(e) describe the cause and means of transmission of malaria and discuss its global impact and why it is difficult to control

(f) explain the term autoimmune disease with reference to type 1 diabetes and myasthenia gravis

(g) outline the ABO blood group system and discuss its implications in transfusion and hyperacute rejection of transplanted organs

(h) outline the principles involved in histocompatibility and acute transplant rejection (details of the MHC system are not required)

(i) outline the production of monoclonal antibodies and explain why it is necessary to use hybridoma cells for this purpose

(j) discuss and evaluate the use of monoclonal antibodies compared to conventional methods for diagnosis and treatment including pregnancy testing, diagnosis of HIV/AIDS and radioimmunotherapy of cancer

Practical learning outcomes

Cross reference Section 3.1, Practical Learning outcome (i)

3.6 Reproduction

Content

Human sexual reproduction

Cloning

Learning outcomes

Candidates should be able to:

(a) outline the structure of the human male and female urinogenital systems

(b) explain the roles of ovarian and anterior pituitary hormones in controlling the menstrual cycle (limited to oestrogen, progesterone, FSH and LH)

(c) explain what is meant by *in vitro* and *in vivo* fertilisation

(d) explain the roles of the placenta in pregnancy to include the transfer of materials, isolation of fetus from maternal blood and production of hormones (including chorionic gonadotrophin, oestrogen and progesterone and human placental lactogen)

(e) explain what cloning is and discuss ethical issues relating to the use of cloning in animals and humans (including production of cattle and therapeutic cloning)

Practical learning outcomes

Candidates should be able to:

(i) explain the relationship between structure and function of mammalian testis, ovary (including follicles and corpus luteum) and placenta using histological sections and electronmicrographs

4. The life of plants

Plants provide us with the material to study many biological principles. We ignore them at our peril as they are the foundation of almost all food chains and provide us, directly or indirectly, with most of our food and many economically important products. This section explores several aspects of their physiology – from their highly adaptable transport systems to the great variety of methods of reproduction and ultimate reliance on sunlight.

These questions may be put to candidates to stimulate discussion and prompt and direct their own researches while covering Section 4.

- How do plants transport materials?
- How does water get to the top of a redwood tree that is over 110 m high?
- Why are plants called producers?
- Why do we neglect plants 'at our peril'?
- How do plants control themselves?
- Why do some plants produce flowers, seeds and fruits?

4.1 Transport in plants

Content

Transport of water in the xylem

Transport of assimilates in the phloem

Stomata – structure and function

Learning outcomes

Candidates should be able to:

(a) describe the passage of water through a dicotyledonous plant from soil to atmosphere

(b) describe the structure and function of the xylem of flowering plants and explain the relationship between its structure and functions

(c) explain the role of cohesion-tension in the transport of water in the xylem

(d) describe the structure and function of guard cells

(e) explain the mechanism of opening and closing of stomata

(f) explain the effect of vascular wilt diseases of plants (including Panama disease of bananas)

(g) describe the structure and function of phloem tissue and explain the relationship between its structure and function

(h) explain mass flow in phloem

Practical learning outcomes

Candidates should be able to:

(i) explain the relationship between structure and function of xylem and phloem using histological specimens from plant transport systems including prepared slides and electronmicrographs

4.2 Photosynthesis

Content

Light-dependent stage

Light-independent stage

Photorespiration

Learning outcomes

Candidates should be able to:

(a) explain the relationship between the light-dependent and light-independent stages of photosynthesis within the chloroplast of a C3 plant

(b) use chromatography to identify key photosynthetic pigments (limited to chlorophylls a and b, carotene and xanthophyll) and interpret absorption and action spectrum graphs

(c) explain the distribution of photosynthetic pigments and their function inside the C3 chloroplast

(d) explain that electrons may gain energy from sunlight and that this energy may be used to do work

(e) explain the production of ATP and reduced NADP during the light-dependent stage (including roles of photosystems 1 and 2, electron transport chain, generation of proton gradient, cyclic and non-cyclic photophosphorylation)

(f) explain the Calvin cycle (RuBP and fixation of carbon dioxide to form GP followed by its reduction to form triose phosphate and regeneration of RuBP)

(g) outline the use of Calvin cycle intermediates to generate a range of organic molecules

(h) discuss the importance of the enzyme rubisco and its vulnerability to competitive inhibition by oxygen during photorespiration

(i) outline the impact of high light intensities and temperatures on the rate of photorespiration

(j) explain, in outline, how C4 and CAM plants reduce the impact of photorespiration by isolating the light-independent stages from the oxygen in the air (limited to the means used to produce spatial separation [C4] and temporal separation [CAM]. Biochemical details of the C4 pathway are not required)

Practical learning outcomes

Candidates should be able to:

(i) investigate the Hill reaction using a chloroplast suspension and DCPIP

(ii) investigate the structure of chloroplasts using electronmicrographs

(iii) carry out paper or thin layer chromatography to separate and identify key photosynthetic pigments

(iv) compare the leaf anatomy of C3 (e.g. *Ligustrum*, *Triticum*), C4 (e.g. *Zea mays*) and CAM (e.g. *Crassula*) plants under the light microscope

4.3 Reproduction

Content

Pollination

Fertilisation

Seeds and fruit

Learning outcomes

Candidates should be able to:

(a) state what is meant by the terms self-pollination and cross-pollination and explain the advantages and disadvantages of each (including reference to inbreeding)

(b) explain the means by which flowering plants transfer the male gametes and ensure that they arrive in the correct place for fertilisation limited to:

- wind pollination including adaptations of anthers, pollen and stigmatic surface
- insect pollination including reference to UV light, guides, nectar, odours, imitation of female insects
- chemotropic growth of pollen tube to embryo sac

(c) outline the role of meiosis in the development of pollen and embryo sacs and of mitosis in the formation of gametes

(d) explain the significance of double fertilisation in flowering plants and describe the development of seeds and fruits (including one endospermous seed and one non-endospermous seed)

Practical learning outcomes

Candidates should be able to:

(i) investigate pollination mechanisms and pollen structure as well as growth of the pollen tube in living pollen

(ii) investigate a variety of flowers showing a range of adaptations (e.g. wind pollination and insect pollination)

(iii) investigate the structure of seeds and fruits using specimens of endospermous seeds, such as maize, and non-endospermous seeds, such as those of legumes

(iv) investigate seed and fruit development using fresh specimens and prepared slides of Shepherd's purse, *Capsella bursa-pastoris*

4.4 Control of plant processes

Content

Genetic control of plant cell growth

Role of membrane transporters in phototropism

Mode of action of gibberellins and auxins

Learning outcomes

Candidates should be able to:

(a) state that, in the absence of gibberellins or auxins, flowering plant cell growth is restricted by transcription blocking factors that block the transcription of genes responsible for cell growth

(b) describe how both gibberellins and auxins promote plant cell growth

(c) explain how gibberellins promote stem elongation in flowering plants by controlling cell elongation

(d) explain how mutant alleles for gibberellin synthesis have led to dwarf rice and mutant alleles for synthesis of DELLA protein have led to dwarf wheat, in both cases increasing yield because a greater proportion of energy is put into grain

(e) explain the existence of Mendel's tall and dwarf pea plants in terms of a pair of alleles, the dominant allele, *Le*, coding for a functioning enzyme in the gibberellin synthesis pathway, the recessive allele, *le*, coding for a non-functional enzyme

(f) explain the role of auxins in positive phototropism of stems

Practical learning outcomes

Candidates should be able to:

(i) investigate phototropism in coleoptiles or other young shoots including unilateral application of auxin from excised coleoptile tips or auxin in a gel

(ii) investigate the effect of gibberellins on dwarf/bush pea or sweet pea seedlings

(iii) investigate whether plants with a basal rosette of leaves have non-functional gibberellin genes by adding gibberellins

5. Environmental studies

This section deals with life on a global scale – the interactions between life and the environment. It takes a look at the huge variety of life and why organisms live in the places they do. The section also considers the impact of climate change and the ways in which we are able to protect and conserve biodiversity.

This section could form a key part of a 3–4 day residential field course, or for situations where this is not possible, could be accomplished by a series of fieldwork sessions in the local environment of the Centre, whether this be urban or rural. The same organisms could be studied in outcomes 5.1 (a) and (b) so that candidates are able to form a coherent understanding of the adaptations of the organisms and the way in which these suit the organism to the niche that it occupies.

It is important that at least one of these organisms can be studied in detail in a natural, wild or semi-wild environment (which could include, for example, organisms encountered during a field course, or wild birds or weeds in the school grounds).

These questions may be put to candidates to stimulate discussion and prompt and direct their own researches while covering Section 5.

- What determines where a particular organism lives and what it does there?
- How does adaptation relate to success for organisms/species?
- Why are tropical ecosystems so different from temperate and polar ones?
- What do changes in the global climate mean for the life of plants?
- Why are large fierce animals rare and why should they be conserved?
- How many species are there? And why are there so many?
- What is the smallest part of an ecosystem that can be conserved successfully?

5.1 Adaptation

Content

Adaptation and the ecological niche

Learning outcomes

Candidates should be able to:

(a) explain what is meant by the term adaptation by reference to specific physiological and behavioural adaptations of a named bird (e.g. starling or dunnock) and a motile protoctist (e.g. a ciliate or a motile photosynthetic protoctist)

(b) discuss how the niche concept and adaptation explain the distribution of organisms within habitats

(c) explain how an individual's adaptive behavioural strategy can vary within a species, making particular reference to dunnock and red deer

(d) explain the global distribution of C3 and C4 plants and discuss the potential impact of climate change on future patterns of agriculture

(e) discuss the stomatal and other adaptations characteristic of flowering plant species living in a variety of habitats (including hydrophytes and xerophytes)

Practical learning outcomes

Candidates should be able to:

(i) undertake a detailed investigation of the relationship between adaptation, the distribution of organisms and their niches for wild, semi-wild or captive organisms, observed directly or on screen

(ii) study leaves from flowering plants adapted to a variety of habitats, including hydrophytes (e.g. *Nymphaea* or *Nuphar*) and xerophytes (e.g. *Erica* or *Nerium*)

5.2 Measuring and conserving biodiversity

Content

Biodiversity

Sampling techniques as ecological tools

Principles of conserving biodiversity

The species-area concept

Integrated management strategies

Learning outcomes

Candidates should be able to:

(a) explain what is meant by biodiversity with reference to different levels; ecosystem, community, species and genetic

(b) use, or interpret secondary data from, quantitative and qualitative techniques for measuring biodiversity and abundance, including diversity indices, percentage cover, species density, direct counts, relative abundance scales (e.g. ACFORN)

(c) explain how to estimate population size using mark-release-recapture and the Lincoln index

(d) discuss the importance of conservation and the types of information needed to inform conservation strategies

(e) explain the concept of the keystone species and discuss the consequences of the loss of such species on biodiversity

(f) discuss the importance of conserving biodiversity for social, ethical, medical, economic and environmental reasons

(g) outline the species-area concept in terms of the positive correlation between the species-richness of an ecosystem and its area

(h) discuss the implications of the species-area concept in conservation strategies including the danger of habitat fragmentation and the importance of corridors

(i) discuss the SLOSS debate [Single Large Or Several Small reserves]

Practical learning outcomes

Candidates should be able to:

(i) undertake an ecological survey of at least one ecosystem using appropriate methods, such as open and grid quadrats, point quadrats, line transect, belt transect and methods for measuring abiotic factors

(ii) determine the diversity of an ecosystem by calculating Simpson's index of diversity or another appropriate index

(iii) determine the population of a small animal using the mark, release recapture method and calculate the Lincoln index (alternatively this may be modelled)

Appendix 1: Practical assessment

Introduction

Candidates should be given opportunities for the practice of experimental skills throughout the whole period of their course of study. As a guide, candidates should expect to spend at least 20% of their time doing practical work individually or in small groups. This 20% does not include the time spent observing teacher demonstrations of experiments and simulations. The practical work that candidates do during their course should:

- provide learning opportunities so that candidates develop the skills they need to carry out experimental and investigative work
- reinforce the learning of the theoretical subject content of the syllabus
- instil an understanding of the interplay of experiment and theory in scientific method
- prove enjoyable and rewarding

Practical assessment will be through Component 3, a practical examination paper. Candidates should keep records of the practical work they carry out during their course.

The planning aspect of practical assessment will be examined in Component 2 along with data analysis, interpretation and evaluation. Component 3, a practical examination paper, will not formally assess planning, but will assess all the other skills described below. Candidates will not be presented with a complete set of instructions to follow in the practical examination: they will be expected to make decisions about such things as concentrations to prepare and number of measurements to take. Experience of planning and carrying out investigations will be essential preparation for the practical examination.

It should be stressed that candidates cannot be adequately prepared for planning, data analysis, interpretation and evaluation in Component 2 and the practical assessment in Component 3 without extensive laboratory work during their course of study.

Component 3

The examiners may not be strictly bound by the subject content of the syllabus in finding contexts for the setting of questions. Within unfamiliar contexts, candidates will be told exactly what to do and how to do it. Within familiar contexts listed in the syllabus, the candidates will be expected to know how to use the techniques and make appropriate decisions on their application. Knowledge of theory and experimental skills will be drawn only from within the syllabus. Examples of unfamiliar contexts might include:

- following instructions to set up and use unfamiliar equipment
- following instructions to use unfamiliar biochemical procedures
- making microscopic observations, drawing and magnification calculations from unfamiliar structures or specimens
- making observations and deductions from photographs, photomicrographs, electronmicrographs and specimens

Component 3 will consist of two sections, A and B. Both sections will be laboratory-based practicals requiring skills of experimentation, observation, presentation, analysis, deduction and evaluation.

Section A will consist of one or two questions totalling 45 marks. It should be completed in about 90 minutes. It will include an experiment or experiments requiring candidates to collect quantitative or qualitative data, to draw up tables, charts, graphs and other appropriate means of presenting the data and to analyse it to draw appropriate conclusions and evaluate procedures and data.

It will focus on the following experimental skills:

- manipulating apparatus
- decision-making
- recording observations and measurements
- presenting data
- calculating, e.g. rates of reaction
- analysing data – describing experimental results, observations and secondary data
- concluding
- evaluating procedures and data
- suggesting improvements

Apparatus requirements for Section A

The apparatus requirements for Section A will vary from paper to paper. A complete list of apparatus and materials required for each question will be issued in the Confidential Instructions. The Confidential Instructions should be followed very carefully. If there is any doubt at all about how practical examinations should be set up, it is vital that Centres contact CIE as soon as possible.

To give some variation in the questions set, some novel items or equipment or materials may be required. The list of practical apparatus and materials later in the syllabus gives details of the requirements that are frequently required. Candidates should be accustomed to using these.

Section B will consist of one or more short questions totalling 35 marks. It should be completed in 60 minutes. The questions will test the candidates' abilities to make observations and present, analyse and interpret their findings. Candidates will be expected to use a microscope to observe and draw from histological specimens that they have made themselves as temporary mounts or which are provided as prepared slides. Candidates will also be provided with secondary data to analyse and interpret. This secondary data may be in the form of photographs, drawings, diagrams, tables and graphs. Section B will concentrate on the following skills:

- decision making
- observing
- presenting information in the form of plan diagrams, drawings, tables, etc.
- calculating, e.g. magnifications and actual sizes
- analysing data – describing and interpreting experimental results, observations and secondary data
- evaluating

Throughout their course, candidates should be given opportunities to make decisions about their practical work. This might involve choosing the number of values of the independent variable and the number of replicates. It might also involve deciding how to make up dilutions. They should also plan complete experiments to include methods of data collection and analysis. Candidates taking the practical examination will be expected to have the appropriate skills involved in decision-making and planning even though candidates will not be expected to plan a complete experiment in this examination.

The development of these skills requires many hours of laboratory-based work, and it also requires careful supervision from teachers to ensure that experiments are performed with due regard to safety.

For both Section A and B, some questions may include secondary data particularly if they are set in areas of biology that are difficult to investigate experimentally in school laboratories, either because of the cost of equipment, such as colorimeters or large fermenters, or because of restrictions on the availability of samples and materials, such as living individuals of rare species, or radioactive materials to be used as markers. No question will require knowledge of theory or equipment that is beyond the Pre-U syllabus. Information that candidates are not expected to know, but is needed by candidates to allow them to use the data, will be provided in the examination paper. The amount of information will be limited to ensure that there is ample time for candidates to read and consider the information.

Candidates may start with Section A or Section B. They will need the use of a microscope in Section B for at least 30 minutes. The timings for the questions are recommended timings. Candidates should be advised not to spend longer on each question than the timings given on the examination paper.

Assessment of skills in Components 2 and 3

Practical assessment will involve the testing of five skill areas. Each skill area is divided into relevant sub-skills. Details of the sub-skills are given in the next few pages.

Skill	Sub-skills
Planning and decision-making	• Defining the problem • Choosing appropriate techniques • Determining number of measurements/observations to take
Manipulation, measurement and observation	• Successful collection of data and observations • Decisions about measurement or observations
Presentation of data and observations	• Recording data and observations in tables and other suitable forms • Presenting data in the form of graphs and charts
Analysis of data and conclusions	• Display of calculation and reasoning • Description of patterns and trends • Interpretation of data and observations • Making conclusions drawing on theoretical knowledge and understanding
Evaluation of procedures and data	• Identifying limitations and sources of error • Suggesting improvements

Skill Area — Planning and decision-making

Sub-skill
Defining the problem
Candidates should be able to:

- identify the dependent and independent variables in an investigation or experiment
- express the aim in terms of a prediction or hypothesis, and express this in words and, if appropriate, in the form of a predicted graph
- identify the variables that are to be controlled
- decide on a control experiment or experiments (if appropriate)

Candidates will be provided with a scenario and background information to set the context within which they are expected to define the problem. They should be able to make use of this information to identify the key variables in the investigation. Candidates should be able to make a hypothesis. This should be a quantitative, testable, falsifiable prediction of the likely outcome, based on the information given and their knowledge and understanding of the topic under consideration. Candidates may be asked to express their hypothesis in the form of a sketch graph showing the expected outcome. A list of key variables to control in order to test the hypothesis effectively is required, and should include only variables that might be expected to have some effect on the material involved (e.g. temperature), but not those likely to have a trivial effect.

Sub-skill
Choosing appropriate techniques
Candidates should be able to:

- describe the method to be used to vary the independent variable, and the means that they will propose to ensure that they have measured its values accurately
- describe how the dependent variable is to be measured
- describe how each of the other key variables is to be controlled
- explain how any control experiments will be used to verify that it is the independent variable that is affecting the dependent variable and not some other factor
- describe the arrangement of apparatus and the steps in the procedure to be followed
- suggest appropriate volumes and concentrations of reagents, and explain how different concentrations would be prepared
- assess the risks of their proposed methods
- describe precautions that should be taken to keep risks to a minimum
- draw up tables for data that they might wish to record
- describe how the data might be used in order to reach a conclusion

The overall arrangement should be workable. It should be possible to collect the data required without undue difficulty if the apparatus were assembled as described. Words and labelled diagrams should be used for describing the apparatus and how to use it. The measuring instruments chosen should measure the correct quantity to a suitable precision. Control experiments may be of the type where all factors are identical to the experimental treatment, except that the value of the independent variable is zero, or they may be of the type used to confirm that, for example, it is an enzyme that is causing a particular effect, where the enzyme is omitted or denatured.

Candidates should be able to explain how to make up solutions:

- in % (w/v), e.g. by adding a known mass of solute to a small volume of solvent, mixing until fully dissolved and then making up to the final volume with solvent
- in mol dm^{-3}, by dissolving the molar mass of solute and then making up to 1 dm^3 with solvent
- by using serial dilution to make up a wide range of dilutions, e.g. by factors of 2 or 10
- by proportional dilution in order to make up a narrow range of dilutions

Candidates should be able to carry out a simple risk assessment of their planned investigation, identifying the areas where accident or injury is most likely and would be most serious. They should be able to use this to propose appropriate safety precautions specifically related to the risks that they have identified – e.g. they might identify that protease enzyme solutions pose a particular risk to the cornea if they are splashed, and that therefore the wearing of eye protection would be an appropriate precaution.

Candidates should be able to describe the main steps that they would use in order to get to the point of being able to draw conclusions, including, as appropriate, preparation of results tables, proposed graphs to plot, key points to consider in any evaluation of the method and results, and reference back to the hypothesis.

Sub-skill
Determining number of measurements and/or observations to take
Candidates should be able to:

- choose a suitable range of values for the independent variable in an investigation
- choose a suitable number of intermediate values for the independent variable
- decide how many replicates to take of each value of the independent variable to ensure reliability (reproducibility) of results
- decide how many observations to take in an investigation that generates qualitative data

Candidates should apply their knowledge and understanding of methods of analysis and evaluation to ensure that they plan to take enough readings of the independent variable to be able to draw a graph and/or make valid conclusions. They should also be aware of the variability of results in biological investigations so that they plan to take enough replicates to carry out a statistical analysis (see **Notes on the uses of statistics in biology** below).

Skill Area Manipulation, measurement and observation

Sub-skill
Successful collection of data and observations
Candidates should be able to:

- set up apparatus correctly
- follow instructions given in the form of written instructions, flow charts or diagrams
- use their apparatus to collect an appropriate quantity of data or observations, including subtle differences in colour or other properties of materials
- make measurements using millimetre scales, graticules, protractors, stopwatches, balances, measuring cylinders, syringes, thermometers, and other common laboratory apparatus

In assessing the accuracy of a candidate's data, the examiners will only consider the extent to which the candidate has affected the quality of the data: allowances will be made where the quality of data is limited by the experimental method required or by the apparatus and materials used. In making such assessments of accuracy, the scatter of points on a graph may be examined, or the candidate's data or observations may be compared with information supplied by the Supervisor.

Marks may be awarded for:

- measured quantitative data in which the values obtained are reasonable
- qualitative observations consistent with the materials supplied

It is important that sufficient distinct observations are made, for example to:

- show all the structures that can be seen in a defined part of a specimen
- identify the dissolved substances in a solution

Candidates will be expected to use light microscopes. They should be able to place the slide on the stage, arrange the lighting appropriately and focus on the specimen at both low-power (×10, sometimes described as 16 mm or 2/3") and high-power (×40, or 4 mm or 1/6") using a microscope with a graticule fitted into the eyepiece.

Sub-skill
Decisions about measurements or observations
While carrying out an investigation, candidates should be able to:

- decide how many tests, measurements or observations to perform
- make measurements or observations that span the largest possible range within the limits either of the equipment provided or of the instructions given
- make qualitative observations and/or quantitative measurements that are appropriately distributed within this range
- decide how long to leave experiments running before taking readings
- replicate observations, readings or measurements as necessary
- make and record sufficient, accurate measurements and observations

Candidates may need to choose how many tests, measurements and observations can be made in the time available. In some experiments a regularly-spaced set of measurements will be appropriate. For other experiments, such as those requiring the peak value of a curved graph to be determined, it may be appropriate for the measurements to be concentrated in one part of the range investigated. Candidates will be expected to be able to identify the most appropriate distribution of values. In qualitative experiments, precise descriptions and comparisons of colour or other observations are expected.

In experiments such as those involving enzymes:

- initial rate of reaction may be measured (in which case measurements should be conducted as quickly as practicable)
- the rate of reaction might be expected to be constant over several minutes, or colour changes may take several minutes to occur, in which case leaving the experiment to run for as long as possible may be appropriate
- an end point may be sought, in which case candidates should expect to run the experiment until the end point is achieved or the time runs out.

Repeated readings of particular quantities are often necessary in biology, where experimental errors and variation in the activity of biological materials are large and an average value would be more representative. Individual readings or observations should be repeated where they appear to be anomalous. It may be necessary for the candidate to decide how many times to let something that is repetitious occur before recording the observation (e.g. in counting the number of bubbles released from a delivery tube).

Skill Area — Presentation of data and observations

Sub-skill
Recording data and observations in tables and other suitable forms
Candidates should be able to:

- present numerical data, values or observations in a single table of results
- draw up the table before taking readings/making observations, so that candidates can record directly into the table, to avoid the need to copy up their results
- make tables of data and observations large enough so that all the entries can be comfortably fitted in the available space
- include in the table of results, if necessary, columns for raw data, for calculated values and for deductions
- use column headings that include the quantity and the unit (as appropriate) and that conform to accepted scientific conventions
- record raw readings of a quantity to the same degree of precision and observations to the same level of detail
- follow the Society of Biology recommendations for constructing tables
- make drawings large and un-shaded so that errors are small, and use fine, clear, unbroken lines, showing clear outlines of structures
- use pencil for drawings and lines on tables

As an example of accepted practice in column headings, if the quantity being measured is length in millimetres, then this should be expressed as 'length/mm' or 'length (mm)'. Headings such as 'length', 'length mm', or just 'mm' are not acceptable. The quantity or the unit or both may be written in words or appropriate symbols may be used provided that their meaning is clear and unambiguous in the context. Avoid *t*, since it may be used for time and for temperature. Conventional symbols or abbreviations such as *r* for radius, may be used without explanation.

In recording data and observations, if one measurement of length in a column of raw data is given to the nearest millimetre, then all the lengths in that column should be given to the nearest millimetre. The degree of precision used should be compatible with the measuring instrument used: it would be inappropriate to record a distance measured on a millimetre scale as '2 cm' or a time to 1/10th of a second. Where the calibration marks on a measuring instrument are widely spaced, it may be appropriate to interpolate between the marks, but where the calibration marks are close together then the reading should be to the nearest calibration mark. See **http://www.chemsoc.org/networks/learnnet/RSCmeasurements.htm** for more information on measurement.

Observations of qualitative variables such as colour should be recorded in simple language such as 'blue' or 'orange'. Where fine discrimination is required, terms such as 'pale' or 'dark' should be used as well, and comparisons made such as 'darker red than at 3 minutes' or 'paler green than at 0.2 mol dm^{-3}, but darker than at 0.4 mol dm^{-3}'. It is important to avoid ambiguous descriptions of colour such as 'pinkish purple' or 'yellowy-green'. Candidates should be able to describe positive and negative results of the biochemical tests in the syllabus precisely, using terms such as 'purple' for the positive result of the biuret test, for example.

Sub-skill
Presenting data in the form of graphs and charts
Candidates should be able to:

- present data in the form of charts, graphs, drawings or mixtures of methods of presentation
- select the most appropriate form of presentation for the data collected or provided, e.g. bar chart, histogram and line graph
- select which variable(s) to plot and plot appropriately on clearly labelled *x*- and *y*-axes
- plot all points or bars to an appropriate accuracy
- follow the Society of Biology recommendations for putting lines on graphs

Generally, candidates are expected to present data in the form in which the key points of the data can be most easily visualised:

- for quantitative data, this is likely to be a graph
- for qualitative data this may be a table

Candidates should:

- choose scales for the graph axes that allow the graph to be read easily, such as 1, 2 or 5 units to a 20 mm square
- make the best use of the space available, using over half of the length and width of the grid
- use pencil for lines on graphs

The accepted scientific conventions for labelling the axes of a graph are the same as for the column headings in a table of results with both the quantity and the unit shown (where appropriate). Points should be finely drawn with a sharp pencil, but must still be visible. A fine cross or an encircled dot is suitable; a thick pencil blob is not. Often it is obvious that the data fall on a straight line or smooth curve, when a line of best fit or appropriate curve should be placed on the graph. Sometimes it is not possible to be sure if the line should be straight or a smooth curve, so adjacent points should be joined by straight ruled lines in order to represent the data with the minimum of assumptions. Lines of best fit should show an even distribution of points on either side of the line along its whole length. Lines should be finely drawn and should not contain kinks or breaks. If error bars are placed onto graphs, then the line of best fit must go through those error bars.

Skill Area — Analysis of data and conclusions

Sub-skill
Display of calculations and reasoning
Candidates should be able to:

- show their working in calculations, and the key steps in their reasoning
- use the correct number of significant figures for calculated quantities

Where calculations are done, all of the key stages in the calculation should be recorded by candidates, so that credit can be given for correctly displaying working even if the final answer is incorrect. Similarly, where observations form the basis for logical deduction (e.g. the concentration of an unknown solution or the identity of an unknown solute), the main steps in making the deduction should be shown. Again, where inductive thought processes are used to build up a general prediction or to support a general theory, from specific observations, the sequence of major steps used should be reported.

Calculated quantities should be given to the same number of significant figures as the measured quantity that has the smallest number of significant figures. For example, if values of time and of volume of gas collected are measured to 1 and 2 significant figures respectively, then the calculated rate should be given to 1 significant figure, but not 2 or more.

See **http://www.chemsoc.org/networks/learnnet/RSCmeasurements.htm** for more information on significant figures.

Sub-skill
Description of patterns and trends
Candidates should be able to:

- use tables and graphs to draw attention to the key points in quantitative data, including the variability of data
- describe the patterns and trends shown by data in tables and graphs
- describe and summarise the key points of a set of observations

Descriptions of patterns and trends should be precise, giving quotations of figures to support the description, and calculated values where these are appropriate.

Sub-skill
Interpretation of data and observations
Candidates should be able to:

- identify the calculations that are necessary to be able to draw conclusions from primary and/or secondary data
- use descriptive statistics to enable simplification of data, assess its variability and determine the confidence in the validity of conclusions
- use appropriate statistical tests to determine goodness of fit and the statistical differences between samples
- find an unknown value by using co-ordinates or axis intercepts on a graph
- calculate other quantities from data or from quantitative data related to their qualitative observations, or calculate the mean from replicate values, or make other appropriate calculations
- determine the gradient of a straight-line graph or tangent to a curve

Candidates should know how to choose and carry out calculations required for simplifying data and to make them comparable. These may involve determining the following:

- mean
- median
- mode
- percentages
- percentage gain or loss
- rate of reaction
- magnification and actual size

Candidates should know how to select and carry out the key steps of descriptive statistical methods designed to assess variability in data including

- range
- inter-quartile range
- standard deviation
- standard error

Candidates should know how to put error bars on graphs which may be calculated using standard error.

Candidates should be able to select and use, when provided with suitable equations, statistical tests designed to find the differences between samples:

- chi squared test
- *t*-test

They should also know how to use Spearman's rank and Pearson's linear correlation to test for correlation. See the **Notes on the use of statistics in biology** at the end of this syllabus.

Candidates may be expected to derive unknown values which might include concentrations where a calibration curve has been drawn. When a gradient is to be determined, the points on the line chosen for the calculation should be separated by at least half of the length of the line or tangent drawn.

Candidates should be encouraged to use spreadsheets to collate and analyse the data they collect in their own practical work or when analysing secondary data. This makes it possible to assess the variability of their data.

Sub-skill
Making conclusions drawing on theoretical knowledge and understanding
Candidates should be able to:

- draw conclusions from an investigation or from interpretations of observations, data and calculated values, providing a detailed description of the key features of the observations, data and analyses, and considering whether experimental data support a given hypothesis or not
- make detailed scientific explanations of the data and of their conclusions, drawing on the skills, knowledge and understanding that they have gained from their studies of the Pre-U syllabus
- make further predictions and ask informed and relevant questions

Key points of the raw data, graphical representations of it and statistical test results should be given, including quoting of relevant figures, leading to a clear indication of the strength or weakness of any support for or against the hypothesis, or indeed, its proof or refutation. Conclusions may be expressed in terms of support for, or refutation of, hypotheses, or in terms of the straightforward deductions or inductions that, logically, can be made from the data, observations or results of calculations. Detailed scientific explanations form a part of such conclusions and therefore form a part of this higher-order practical skill assessment, in which the candidates will be expected to refer to knowledge and understanding gained in the theoretical part of the course in order to provide explanations of their practical conclusions, for example making detailed reference to changes in protein structure when interpreting the effect of pH on enzyme activity.

Skill Area — Evaluation of procedures and data

Sub-skill
Identifying limitations and sources of error
Candidates should be able to:

- make criticisms of the experimental procedure
- evaluate the effectiveness of control of variables and thus the confidence with which conclusions might be drawn
- identify the most significant sources of error in an experiment
- estimate, quantitatively, the uncertainty in quantitative measurements
- express such uncertainty in a measurement as an actual or percentage error
- show an understanding of the distinction between systematic errors and random errors
- Identify anomalous values in provided data and suggest appropriate means of dealing with such anomalies
- Within familiar contexts, suggest possible explanations for anomalous readings
- Identify the extent to which provided readings have been adequately replicated, and describe the adequacy of the range of data provided
- Use provided information to assess the extent to which selected variables have been effectively controlled
- Use these evaluations and provided information to make informed judgements on the confidence with which conclusions may be drawn

In a table or graph of data, candidates should be able to identify values which are clearly anomalous, and suggest strategies for dealing with such anomalies, including repeating the experiment or omitting the affected replicate. Where investigations are set in familiar contexts that candidates are expected to have explored during the course, candidates may be asked to suggest possible causes for such anomalies (above and beyond 'investigator error'), and will be rewarded for answers derived from their own experience of problems intrinsic in the particular investigation.

Candidates should be used to looking at experiments and assessing the relative importance of errors in measurement or in making observations so that they can judge which sources of error are most important. Candidates should be familiar with simple means of estimating error, such as the errors intrinsic in measuring devices or in the observer's ability to observe, or in experiments where limitations of the method introduce errors (e.g. heat loss when trying to assess the energy content of biological materials). They should be able to express these errors in standard forms such as length = 73 mm ± 1 mm, or temperature increase = 14 °C ± 4 °C.

Candidates should be able to suggest which of the sources of error described are likely to be systematic errors such as those resulting from thermometers that consistently read 1 °C above actual temperature, or candidates who read volumes to the wrong part of the meniscus, as well as those which are likely to be random errors due to the variability of biological materials, or random variations in environmental conditions such as room temperature.

For key controlled variables, candidates should be able to give a realistic estimate or appraisal of how effectively the variable was controlled, for example, how constantly the temperature was maintained across a number of samples, and from this, give an indication of the confidence that they would have in any conclusions drawn.

Candidates may be provided with information that will permit them to assess the extent to which a particular variable has been effectively controlled (e.g. the temperature recorded within each of a number of samples in which it is supposed to be the same).

Candidates should be able to draw together all of this information to make informed judgements about the reliability of the investigation and the confidence with which conclusions may be made.

Sub-skill
Suggesting improvements
Candidates should be able to:

- suggest modifications to an experimental arrangement that will improve the accuracy of the experiment or the accuracy of the observations that can be made, including the use of new methods or strategies to investigate the question
- describe such modifications clearly in words or diagrams

Candidates will be expected to have knowledge of the advantages of replication of data, and the practical limitations. Candidates will be expected to be able to identify instances where it would have been sensible to take readings at lower or higher values of the independent variable in order to give a complete range of values, and also situations where there are gaps in the range that reduce the information that can be provided from the investigation (e.g. around a key turning point) and where intermediate readings should be taken.

Candidates' suggestions should be realistic, so that in principle they are achievable in practice. The suggestions may relate either to the apparatus used or described in the question, or to the experimental procedure or to the nature of the observations or the means used to make them. Candidates may include improvements that they would make, such as repeating readings. The suggested modifications may relate to sources of error identified by the candidate or to other sources of error.

Where appropriate, candidates may be given the opportunity to ask questions based on their conclusions and thus to derive further predictions and hypotheses. In addition, candidates may be asked to suggest ways in which to extend the investigation to answer a new question.

Laboratory equipment

The following is a list of basic materials and apparatus which would be expected for a Centre providing this qualification. However, the list is by no means exhaustive.

In accordance with the COSHH (Control of Substances Hazardous to Health) Regulations, operative in the UK, a hazard appraisal of the list has been carried out.

The following codes are used where relevant.

C = corrosive substance
F = highly flammable substance
H = harmful or irritating substance
O = oxidising substance
T = toxic substance
N = environmentally hazardous substance

General

Test-tubes and large test-tubes (boiling tubes) – some test-tubes should be heat resistant
Test-tube holders or similar means of holding tubes
Test-tube racks or similar in which to stand tubes
Bungs to fit test-tubes/boiling tubes
Specimen tubes with corks
A means of heating – Bunsen burners or similar
Thermometers
Measuring cylinders
Means of measuring small volumes, e.g. syringes (various sizes)
Teat pipettes
Beakers
Tripod stands and gauzes
Filter funnels and filter paper
Petri dishes (plastic) or similar small containers
White tiles or other suitable surface on which to cut
Glass slides and coverslips
Conical flasks
Clamp (retort) stands and bosses
Visking (dialysis) tubing
Capillary tubing
Soda glass tubing
Paper towelling or tissue
Cotton wool
Solid glass rods
Black paper/aluminium foil
Means of writing on glassware (water resistant markers)
Hand lenses (not less than ×6, preferably ×8)
Forceps
Scissors

Mounted needles
Cutting implement, e.g. solid-edged razor blade/knife/scalpel
Mortars and pestles
Safety spectacles or other suitable eye protection
Microscope and lamp/inbuilt illumination with high and low power objective lenses (1 each or 1 between 2)
Eyepiece graticules and stage micrometers
Bench lamp with flexible arm
Balance (to 0.01 g)
Water-baths or equivalent
Cork borers
Stopclock/timer showing seconds
Simple respirometer – can be 'homemade'
Pipe cleaners/other suitable aid to demonstrate mitosis and meiosis
Apparatus to measure rate and depth of breathing
Culture bottles, autoclave
Inoculating wires/bioloops
Haemocytometers
Tape for sealing dishes

Stocks of the following chemicals and reagents:
Iodine in potassium iodide solution
Benedict's solution
[**C**] – biuret reagent/potassium hydroxide and copper sulfate solution
[**F**] – ethanol (for fats test)
[**F**] – methylated spirit (extraction of chlorophyll)
Sucrose (use AR for non-reducing sugar test)
Glucose
Starch
[**C**] – Potassium hydroxide
Sodium chloride
Dilute hydrochloric acid
Hydrogencarbonate indicator
Sodium bicarbonate/sodium hydrogencarbonate
Limewater
Distilled/deionised water
Universal Indicator paper and chart
Litmus paper
Neutral red solution or powder
[**H**] – Eosin/red ink
[**H**] – Methylene blue

Vaseline/petroleum jelly (or similar)

DCPIP (dichlorophenol-indophenol)

Ascorbic acid (vitamin C)

[**H**] – Enzymes: amylase, trypsin (or bacterial protease), pepsin, pectinase

Materials for preparing immobilised enzymes: calcium chloride, sodium alginate

Potatoes (store in fridge) or mung beans (to germinate for use) as a source of catalase

Non-competitive enzyme inhibitor (e.g. copper sulfate)

Stains for preparing slides to show mitosis – e.g. carmine acetic, toluidine blue, aceto-orcein

[**H**] – Feulgen stain (Schiff's reagent)

[**H**] – Reagents for Gram staining – solutions of crystal violet, Gram's iodine and safranin

Reagents for paper or thin layer chromatography

Nutrient broth, nutrient agar

Reagents and enzymes for investigation of the *lac* operon – see, for example:

www-saps.plantsci.cam.ac.uk/worksheets/scotland/lac.htm

Reagents, materials and apparatus required for investigations using DNA and electrophoresis – see, for example:

www-saps.plantsci.cam.ac.uk/worksheets/scotland/dna.htm

[**H**] – Appropriate disinfectants

Gibberellin, auxin

Ecological/fieldwork equipment

Apparatus for sampling, e.g. 'open' and 'grid' quadrats, point quadrats

Apparatus for measuring abiotic factors, e.g. oxygen meter, flow meter, etc.

Beating tray ('homemade')

Pooter ('homemade')

Sweeping net (muslin)

Plankton net and dip net (if aquatic environment is being sampled)

Pitfall trap/jam jar; suitable cover to prevent water entry

Trays for hand sorting

Specimens

Flowers of monoecious and dioecious species

Flowers and pollen of wind-pollinated and insect-pollinated plants

Seeds of a C3 plant and of a C4 plant

Cereal seed

Dwarf/bush pea or sweet pea seeds

Variety of endospermous seeds and non-endospermous seeds

Cultures of live yoghurt

Appropriate cultures of microorganisms, e.g. *Escherichia coli*, *Bacillus subtilis*

Insect (e.g. locust or cockroach), fish (complete or head only), and mammalian trachea and lungs to investigate gas exchange systems

Examples of animal and plant cells/tissues to use for temporary mounts

Examples of organisms representing the three kingdoms that are not animals or plants

Protoctista (e.g. *Amoeba*, *Euglena*, *Paramecia*, *Vorticella* or locally available equivalents); Prokaryotae (e.g. bacterial smear, cyanobacteria); Fungi (e.g. yeast, *Penicillium*)

Prokaryote and eukaryote fossils as real specimens, simulations, and various types of image

Prepared microscope slides

Mitosis and meiosis

Anther and ovule

VS fruit of *Zea mays*, VS fruit of *Capsella* or other plant with non-endospermous seeds

TS stem, TS root and TS leaf of a dicotyledonous mesophyte (e.g. *Ligustrum* or *Prunus* or local equivalent)

TS stem, TS leaf of a dicotyledonous hydrophyte (e.g. *Nuphar*, *Nymphaea* or local equivalent)

TS leaf of a xerophyte (e.g. *Erica*, *Ammophila*, *Nerium* or local equivalent)

Stomach and ileum

Pancreas and pituitary gland

Heart, arteries, veins and capillaries

Mammalian blood smear

Liver

Kidney

TS spinal cord, cerebral hemispheres, cerebellum, nerves

Teased myelinated neurones

Teased fibres of striated muscle and motor neurone endings

Ovary, testis and placenta

TS leaf of a C4 plant, e.g. *Zea mays*

TS leaf of a CAM plant, e.g. *Crassula*

Microscale

Centres are encouraged to incorporate some microscale chemistry into their biology Pre-U laboratory work. Manipulative skills on this small scale are becoming increasingly relevant in modern research. The kit is cheap compared to conventional apparatus, and working with such small quantities of chemicals is money-saving. Experiments take much less time and are much less likely to require the sharing of apparatus between candidates; with all the required materials on a personal palette, microscale work generates quiet independent work. Many health and safety barriers are removed by working on such a small scale – risks are minimised when tiny quantities are involved; the experiments can even be done in classrooms rather than laboratories. Quantitative work that involves mass measurement is less advantageously carried out as microscale though, due to the percentage mass errors. Microscale will not be required for practical exams.

Safety in the laboratory

Responsibility for safety matters rests with Centres. Attention is drawn to the following UK associations, websites, publications and regulations.

Associations

CLEAPSS is an advisory service providing support in science and technology, primarily for UK schools. Independent and international schools and post-16 colleges can apply for associate membership which includes access to the CLEAPSS publications listed below, **http://www.cleapss.org.uk/secmbfr.htm**

Websites

http://www.ncbe.reading.ac.uk/NCBE/SAFETY/menu.html

Publications

CLEAPSS Hazcards (see annually updated CLEAPSS Science publications CD-ROM)
CLEAPSS Laboratory handbook (see annually updated CD-ROM)
CLEAPSS Recipe cards (see annually updated CD-ROM)
Safeguards in the School Laboratory, ASE, 11th Edition, 2006
Topics in Safety, ASE, 3rd Edition, 2001
ASE Safety reprints, 2006 or later

Hazardous Chemical: A Manual for Science Education, SSERC, 1997

Hazardous Chemicals. An interactive manual for science education, SSERC, 2nd edition 2002 (CD2)

UK Regulations

Control of Substances Hazardous to Health Regulations (COSHH) 2002,
http://www.opsi.gov.uk/SI/si2002/20022677.htm, a brief guide may be found at
http://www.hse.gov.uk/pubns/indg136.pdf

Appendix 2: Textbooks and IT resources

*Clegg, C J and Mackean, D G *(2000) Advanced Biology: Principles and Applications* (2nd ed) (John Murray, **www.johnmurray.co.uk**) ISBN 0719576709

Clegg, C J, Mackean, D G, Reynolds, R and Openshaw, P *(1996) Advanced Biology Study Guide* (John Murray, **www.johnmurray.co.uk**) ISBN 071955358X

Teachers may find reference to the following books helpful. These titles represent some of the texts available at the time of printing this syllabus. Teachers are encouraged to choose texts for class use which they feel will be of interest to their candidates and will support their own teaching style. Texts with an asterisk (*) indicate those more suitable when choice or availability is limited, and which are most suitable for use as a main text by candidates although these are usually organised in a different way from the syllabus.

Avery, R, Cuthill, I, Miller, R and Rowlands, G *(1994) The Five Kingdoms* Biology Advanced Studies (Nelson Thornes, **www.nelsonthornes.com**) ISBN 0174482299

Biozone *Modular Workbook Series* (Biozone International Ltd., **www.biozone.co.uk**)

Bradfield, P, Dodds, J, Dodds, J and Taylor, N *(2001, 2002) AS Biology, A2 Biology* (Pearson Education Ltd., **www.longman.co.uk**) ISBN 0582429463, 0582429455

Boyle, M and Senior, K *(2002) Biology,* Collins Advanced Science (Collins Educational, **www.collinseducation.com**)

Calladine, C and Drew, H *(1997) Understanding DNA* (2nd ed) (Academic Press, **www.apcatalog.com**) ISBN 0121550885

Campbell, N and Reece, J. *(2009) Biology with Mastering Biology: International Version (8th Ed)* (Pearson Educational, **http://vig.pearsoned.co.uk**) ISBN 978-0321623539

Chapman, J L and Reiss, M J *(1998) Ecology Principles and Applications* (2nd ed) (Cambridge University Press, **www.cambridge.org**) ISBN 0521588022

Clamp, A *(2001) Synoptic Skills in Advanced Biology* (Hodder Murray, **www.hoddereducation.co.uk**) ISBN 0340803223

Gregory, J *(2000) Applications of Genetics* (2nd ed) Cambridge Advanced Sciences (Cambridge University Press, **www.cambridge.org**) ISBN 0521787254

Jones, M, Fosbery, R, Taylor, D, Gregory, J (2007) *CIE Biology AS and A Level* (2nd ed. Cambridge University Press, **www.cambridge.org**) ISBN 978-052170306 2

*Jones, M and Jones, G *(1997) Advanced Biology* (Cambridge University Press, **www.cambridge.org**) ISBN 0521484731

*Kent, M *(2000) Advanced Biology* (Oxford University Press, **www.oup.co.uk**) ISBN 0199141959

Margulis, L, Schwartz, K and Dolan, M *(1999) Diversity of Life: The Illustrated Guide to the Five Kingdoms* (Jones and Bartlett Publishers) ISBN 0763708623

Marieb, E *(2001) Human Anatomy and Physiology* (5th ed) (Benjamin Cummings, **www.aw.com**) ISBN 0805349898

Nicholl, D S T *(2002) An Introduction to Genetic Engineering* (2nd ed) Studies in Biology (Cambridge University Press, **www.cambridge.org**) ISBN 0521004713

Phillips, W D and Chilton, T J *(1994) A-Level Biology* (revised ed) (Oxford University Press, **www.oup.co.uk**) ISBN 0199145849

Ratledge, C and Kristiansen, B *(2006) Basic Biotechnology* (3rd ed) (Cambridge University Press **www.cambridge.org**) ISBN 0521549582

Raven, P,H and Johnson, G.B. *(2010) Biology* (9th ed) (McGraw-Hill Higher Education, **http://catalogs.mhhe.com/mhhe/home.do**) ISBN 978-0071222068

*Roberts, M, Monger, G and Reiss, M *(2000) Advanced Biology* (Nelson Thornes, **www.nelsonthornes.com**) ISBN 0174387326

Spicer, J *(2006) Biodiversity, A Beginner's Guide* (Oneworld Publications) ISBN 1851684719

*Taylor, D J, Green, N P O, Stout, G W and Soper, R *(1997) Biological Science 1 and 2* (3rd ed) (Cambridge University Press, **www.cambridge.org**) ISBN 0521561787

Taylor, J *(2001) Microorganisms and Biotechnology* (2nd ed) Bath Advanced Science (Nelson Thornes, **www.nelsonthornes.com**) ISBN 0174482558

Taylor, D *(2001) Growth, Development and Reproduction* (2nd ed) Cambridge Advanced Sciences (Cambridge University Press, **www.cambridge.org**) ISBN 0521787211

Vardy, P *(1999) The Puzzle of Ethics* (Fount) ISBN 0006281443

Biology Practical Skills books

Teaching AS Biology Practical Skills – PSAS97000105 and Teaching A2 Biology Practical Skills – PSA297000105 (2006) are available from CIE Publications, 1 Hills Road, Cambridge, CB1 2EU, UK, phone +44 (0) 1223 553553, fax +44 (0) 1223 553558, e-mail **international@cie.org.uk**

Adds, J, Larkcom, E, Miller, R and Sutton, R *(2001) Tools, Techniques and Assessment in Biology* (Nelson Thornes Ltd) ISBN 0174482736

Cadogan, A and Ingram, M *(2002) Maths for Advanced Biology*. (Nelson Thornes, **www.nelsonthornes.com**) ISBN: 0-7487-6506-9

Hayward, D *(2003) Teaching and Assessing Practical Skills in Science* (Cambridge University Press, **http://www.cambridge.org/education/international**) ISBN 0521753597 (A resource for teachers to support the delivery of the syllabus – written for IGCSE, but useful for AS and A Level)

Indge, B *(2003) Data and Data Handling for AS Level* (Hodder Murray, **www.hoddereducation.co.uk**) ISBN 0340856475

King, T, Reiss, M and Roberts, M *(2001) Practical Advanced Biology* (Nelson Thornes) ISBN 0174483082

Morgan, S *(2002) Practical Work for Biology* (Hodder & Stoughton, **www.hodderheadline.co.uk**) ISBN 0340847123

Siddiqui, S A *(1999) Comprehensive Practical Biology for A Levels* (Ferozsons, Lahore) ISBN 9690015729

The following may also be useful:

Biological Sciences Review (Philip Allan Updates, **www.philipallan.co.uk**)

Meatyard, B (editor) *(2009) Biological Nomenclature: Standard terms and expressions used in the teaching of Biology* (4th Ed) (Society of Biology **www.societyofbiology.org**) ISBN 978-0-900490-39-2

CD-ROM

BIOSCOPE biological microscope simulation (Edition 2004)
Includes 56 slide sets of plant and animal specimens, with features that give the feeling of a real microsope. Paper-based tasks (in Word and PDF format), each of 45 to 60 minutes duration, accompany the slides. The slide set and tasks meet the needs of the Biology Pre-U syllabus. (Cambridge-Hitachi **http://www.cambridge-hitachi.com**) ISBN 1845650263

Experiment Simulator (Edition 2005)
Developed by Cambridge Assessment, the new Experiment Simulator CD-ROM provides six simulated science experiments to inspire and support candidates, based on real experimental data. It includes superb candidate worksheets and teacher notes. (Cambridge-Hitachi **http://www.cambridge-hitachi.com**)
ISBN 1845651405

Biozone *Teacher Resource Handbook (2005)*

Appendix 3: Mathematical requirements

Candidates should be able to:

- recognise and use expressions in decimal and standard form
- use a calculator for addition, subtraction, multiplication and division, finding the arithmetical mean and to find and use x^2, $\frac{1}{x}$, $\sqrt{x}$, $\log_{10}x$
- take account of accuracy in numerical work and handle calculations so that significant figures are neither lost unnecessarily nor carried beyond what is justified
- make estimations of the results of calculations (without using a calculator)
- recognise and use ratios
- correctly calculate percentages and express changes or errors as percentages and vice versa
- comprehend and use the symbols $<$, $>$, Δ, $\approx$, /, $\propto$, Σ
- calculate areas of right-angled and isosceles triangles, circumference and area of circles, areas and volumes of rectangular blocks and cylinders
- translate information between graphical, numerical, and algebraic forms
- construct and interpret frequency distributions and diagrams, pie charts and histograms
- select appropriate variables and scales for graph plotting using standard 2 mm square graph paper
- for linear graphs, calculate the rate of change
- recognise when it is appropriate to join the points with straight ruled lines and when it is appropriate to use a line (straight or curved) of best fit
- choose, by inspection, a line (straight or curved) which will serve as the best line through a set of data points presented graphically
- understand, draw and use the slope of a tangent to a curve as a means to obtain the rate of change
- understand and use the prefixes: giga (G), mega (M), kilo (k), milli (m), micro (μ), and nano (n).
- have sufficient understanding of probability to understand genetic ratios
- understand the principles of sampling as applied to biological situations and data
- understand the importance of chance when interpreting data
- use a spreadsheet program for collating, analysing and presenting data
- calculate standard deviation and standard error
- understand the benefits of using standard error and 95% confidence intervals (95%CI) to make statements about data and to use as error bars on graphs
- understand the difference between correlation and causation; use Spearman's rank and Pearson's linear correlation to test for correlation
- use the χ^2 test and the *t*-test

Notes on the use of statistics in biology

Candidates should know the distinction between *descriptive statistics* and *statistical tests*. They should also appreciate the requirement to choose appropriate statistical methods *before* planning an investigation in which they will either collect primary data or analyse secondary data. Candidates should have an understanding of the different types of variable and also the different types of data that they may collect or be asked to analyse. These are:

Type of variable	Type of data
Qualitative	
Categoric	Nominal
Ordered	Ordinal (ranked)
Quantitative	
Continuous	Interval (having any value, e.g. 1.0, 2.5, etc.)
Discrete	Interval (integers only, e.g. 1, 2, 3, etc.)

For quantitative data, candidates should understand the difference between a *normal distribution* and a distribution that is non-normal. Candidates should know appropriate descriptive statistical methods to simplify their data. They should be able to use a calculator and/or spreadsheet program to find the mean, median, mode, total range, interquartile range, standard deviation, standard error and 95%CI. Standard error and 95%CI are useful for expressing the reliability of an estimate of the mean and for putting error bars on graphs. Candidates should understand how to apply these methods and explain their significance for their own data and any given data.

Candidates should know when it is appropriate to use a statistical test. They should be able to use statistical tests to test for an association and know when to test for the significance of differences between samples. The chi-squared (χ^2) test is used to test the difference between observed and expected frequencies of nominal data. The chi-squared test allows the evaluation of the results of breeding experiments and ecological sampling. The *t*-test is of value in much of biology to test for the significance of differences between samples. Candidates should be able to use Pearson's linear correlation to test for a correlation between two sets of normally-distributed data and Spearman's rank correlation to test for a correlation between two sets of data that are not distributed normally. They should know that a correlation does not necessarily imply a causative relationship. These statistical methods are dealt with fully in many books and web sites on statistics for biology.

Candidates are **not** expected to remember the following equations and symbols. They **are** expected to be able to use the equations to calculate standard deviations and standard errors (which they may use for error bars on graphs), to test for significant differences between the means of two small unpaired samples and to perform a chi-squared test on suitable data from genetics or ecology. Candidates will be given access to the equations, the meanings of the symbols, a *t*-table and a chi-squared table. In both the *t*-test and the chi-squared test they should be able to calculate the number of degrees of freedom without any reminders. They should appreciate levels of significance and use calculated (or given) values of *t* and χ^2 to make appropriate conclusions.

standard deviation	$s = \sqrt{\frac{\Sigma(x-\bar{x})^2}{n-1}}$	
standard error	$S_M = \frac{s}{\sqrt{n}}$	
t-test	$t = \frac{\left\|\bar{x}^1 - \bar{x}^2\right\|}{\sqrt{\left(\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}\right)}}$	$v = n_1 + n_2 - 2$
χ^2 test	$\chi^2 = \Sigma\frac{(O-E)^2}{E}$	$v = c - 1$

Key to symbols

s = standard deviation	$\bar{x}$ = mean	S_M = standard error	c = number of classes
Σ = 'sum of'	n = sample size (number of observations)		O = observed 'value'
x = observation	v = degrees of freedom		E = expected 'value'

Candidates should note that, on some calculators, the symbol σ may appear instead of the symbol *s*. Candidates are not expected to appreciate the difference between $s_n(\sigma_n)$ and $s_{n-1}(\sigma_{n-1})$. χ^2 tests will only be expected on one row of data.

Questions involving the use of descriptive statistics and the statistical tests described above may be set on Components 1, 2 and 3. The use of a spreadsheet to collate, analyse and present data from an individual or group study could form part of the Optional Formative Assessment.

Electronic calculators will be allowed in the examination, subject to the CIE general regulations.

Glossary of terms used in biology papers

It is hoped that the glossary (which is relevant only to biology) will prove helpful to candidates as a guide, although it does not cover every command word that might be used in biology examinations. The glossary has been deliberately kept brief not only with respect to the number of terms included but also to the descriptions of their meanings. Candidates should appreciate that the meaning of a term must depend in part on its context.

1. *Define* (the term(s)…) is intended literally, only a formal statement or equivalent paraphrase being required.
2. *What do you understand by/What is meant by* (the term(s)…) normally implies that a definition should be given, together with some relevant comment on the significance or context of the term(s) concerned, especially where two or more terms are included in the question. The amount of supplementary comment intended should be interpreted in the light of the indicated mark value.
3. *State* implies a concise answer with little or no supporting argument, e.g. a numerical answer that can readily be obtained 'by inspection'.
4. *List* requires a number of points, generally each of one word, with no elaboration. Where a given number of points is specified, this should **not** be exceeded.
5. (a) *Explain* may imply reasoning or some reference to theory, depending on the context. It is another way of asking candidates to give reasons. The candidate needs to leave the examiner in no doubt **why** something happens.

   Explain how indicates that the candidate should show the way that something works. *Explain why* indicates that the candidate should give the reasons why an event, process or outcome occurs; that the candidate should show what causes the system to do what it does.

   (b) *Give a reason/Give reasons* is another way of asking candidates to explain **why** something happens.
6. (a) *Describe*, the data or information given in a graph, table or diagram, requires the candidate to state the key points that can be seen in the stimulus material. Where possible, reference should be made to numbers drawn from the stimulus material.

   (b) *Describe*, a process, requires the candidate to give a step by step written statement of what happens during the process. *Describe* and *explain* may be coupled, as may *state* and *explain*.
7. *Discuss* requires the candidate to give a critical account of the points involved in the topic. This may include considering the issues, giving information to build an argument, or to permit weighing of both sides of an argument.
8. *Comment* is intended as an open-ended instruction, prompting candidates to make responses appropriate to the context of the question. This may involve evaluating a statement or a hypothesis and is often asked in the context data analysis where evaluation of a procedure and/or assessing the quality of data is expected. Thus candidates may wish to describe, explain, analyse and/or evaluate in response to this command word.
9. *Outline* implies that only the essential points are required, without any supporting detail.
10. *Predict* implies that the candidate is **not** expected to produce the required answer by recall but by making a logical connection between other pieces of information. Such information may be wholly given in the question or may depend on answers extracted in an earlier part of the question.

    Predict also implies a concise answer, with no supporting statement required.

11. *Deduce* is used in a similar way to *predict* except that some supporting statement is required, e.g. reference to a law or principle, or the necessary reasoning is to be included in the answer.

    In multiple choice questions, *deduce* is used to mean that candidates should use the information presented in the question plus their own skills, knowledge and understanding from across the biology syllabus to solve the problem or problems required in order to answer the question.

12. (a) *Suggest* is used in two main contexts, i.e. either to imply that there is no unique answer (e.g. in biology, there are a variety of factors that might limit the rate of photosynthesis in a plant in a glasshouse),

    (b) *Suggest* may also be used to imply that candidates are expected to apply their general knowledge and understanding of biology to a 'novel' situation, one that may be formally 'not in the syllabus' – many data response and problem solving questions are of this type.

13. *Find* is a general term that may variously be interpreted as *calculate*, *measure*, *determine*, etc.

14. *Calculate* is used when a numerical answer is required. In general, working should be shown, especially where two or more steps are involved. Suitable units should be given where possible.

15. *Measure* implies that the quantity concerned can be directly obtained from a suitable measuring instrument, e.g. length, using a rule, or mass, using a balance. Suitable units should be given where possible.

16. *Determine* often implies that the quantity concerned cannot be measured directly but is obtained by calculation, substituting measured or known values of other quantities into a standard formula. It may also be used in the context of a procedure that needs to be carried out so that a numerical answer may be obtained. For example, it may be necessary to find the energy absorbed by a plant so that its efficiency may be calculated.

17. *Estimate* implies a reasoned order of magnitude statement or calculation of the quantity concerned, making such simplifying assumptions as may be necessary about points of principle and about the values of quantities not otherwise included in the question.

18. *Show* is used when an algebraic deduction has to be made to prove a given equation. It is important that the algebraic symbols being used by candidates are stated explicitly.

19. (a) *Sketch*, when applied to graph work, implies that the shape and/or position of the curve need only be qualitatively correct, *but* candidates should be aware that, depending on the context, some quantitative aspects may be looked for, e.g. passing through the origin, having an intercept, asymptote or discontinuity at a particular value. On a sketch graph it is essential that candidates indicate clearly what is being plotted on each axis.

    (b) *Sketch* when applied to diagrams, implies that a simple, freehand drawing is acceptable. Nevertheless, care should be taken over proportions and the clear exposition of important details.

20. *Compare* requires candidates to provide **both** the similarities and differences between things or concepts.

21. *Recognise* is often used to identify facts, characteristics or concepts that are critical (relevant/appropriate) to the understanding of a situation, event, process or phenomenon.

22. *Classify* requires candidates to group things based on common characteristics.

In all questions, the number of marks allocated are shown on the examination paper and should be used as a guide by candidates to how much detail to give. In describing a process, the mark allocation should give the candidate an indication as to how many steps to include. In explaining why something happens, it gives the candidate an indication as to how many reasons to give, or how much detail to give for each reason.

Appendix 4: Performance descriptors

The following grade descriptions indicate the level of attainment characteristic of the middle of the given grade at Pre-U. They give a general indication of the required learning outcomes at each specified grade. The descriptions should be interpreted in relation to the curriculum content in this syllabus, but are not designed to define that content. The grade awarded will depend in practice upon the extent to which the candidate has met the assessment objectives overall. Shortcomings in some aspects of the examination may be balanced by better performance in others.

Distinction (D2)
Candidates recall and use knowledge of biology from the whole syllabus with few omissions and show good understanding of many of the most demanding principles and concepts in the syllabus. They select appropriate information from which to construct arguments or techniques with which to solve problems. In the solution of problems, candidates are usually able to bring together fundamental principles from different content areas of the syllabus and demonstrate a clear understanding of the relationships between these. Candidates show a broad knowledge and understanding of biology consistent with extensive reading around and research.

Candidates apply knowledge and biological principles contained within the syllabus in both familiar and unfamiliar contexts. In questions requiring numerical calculations, candidates demonstrate good understanding of the underlying relationships between quantities involved and carry out all elements of extended calculations correctly in situations where little or no guidance is given. They are often successful on questions which require a combination of applying demanding concepts to unfamiliar contexts, extended problem-solving and synthesis of ideas from different areas of biology.

In practical activities, candidates identify a problem, formulate a clear and effective plan using knowledge and understanding of biology, and use a range of relevant techniques with care and skill. They are organised and methodical in the way they carry out their work and present their results. They make and record measurements which are sufficient and with a precision which is appropriate to the task. They interpret and explain their results with sound use of biological principles and evaluate critically the reliability of their methods.

Merit (M2)
Candidates recall and use knowledge of biology from most parts of the syllabus with some omissions and show good understanding of many of the principles and concepts within it. They select appropriate information from which to solve problems, including some problems in unfamiliar contexts. Candidates show some signs of an ability to bring together fundamental principles from different content areas of the syllabus, but do not do so consistently. They usually make good use of the concepts and terminology of biology in communicating their answers. Candidates show some evidence of knowledge and understanding of biology consistent with some reading and research.

Candidates apply knowledge and principles of biology contained within the syllabus in familiar and some unfamiliar contexts. In questions requiring numerical calculations, candidates demonstrate some understanding of the underlying relationships between quantities involved and are usually aware of the magnitudes of common quantities. Candidates are usually successful in calculations where some structure is provided and can carry out some elements of extended calculations correctly.

In practical activities, candidates are usually able to identify a problem and to formulate a plan, many aspects of which are realistic and practicable. They use a range of relevant techniques with care and skill. They make and record measurements, usually with a precision which is appropriate to the task. They interpret and explain their results using biological principles and make some critical evaluation of their methods.

Pass (P2)

Candidates recall and use knowledge of biology from many parts of the syllabus and demonstrate some understanding of a number of the main principles and concepts within it. Their level of knowledge and understanding may vary significantly across major areas of the syllabus. They select discrete items of knowledge and make some use of information that is presented in familiar ways to solve problems. They make some use of the concepts and terminology of biology in communicating their answers. Candidates show little evidence of knowledge and understanding of biology beyond the defined syllabus content.

Candidates apply knowledge and principles of biology contained within the syllabus to material presented in a familiar or closely related context. They show some understanding of the magnitudes of common quantities when carrying out numerical work. Candidates carry out straightforward calculations in most areas of biology correctly when these calculations are of a familiar kind and when structure is provided, usually using correct units.

In practical activities, candidates are able to plan some aspects of the solution to a practical problem. They make and record appropriate measurements and show some awareness of the need for precision. They usually offer an interpretation of their experimental results making some use of fundamental principles of biology.

Appendix 5: Additional information

Guided learning hours

It is intended that each Principal subject should be delivered through 380 hours of guided learning. This is a notional measure of the substance of the qualification. It includes an estimate of the time that might be allocated to direct teaching or instruction, together with other structured learning time such as directed assignments or supported individual study and practice. It excludes learner-initiated private study.

Certification title

This qualification is shown on a certificate as:

- Cambridge International Level 3 Pre-U Certificate in **Biology (Principal)**.

The qualification is accredited at Level 3 of the UK National Qualifications Framework and provides a solid grounding for candidates to pursue a variety of progression pathways.

Entries

For entry information please refer to the *UK E3 Booklet*.

Grading and reporting

The Cambridge International Level 3 Pre-U Certificates in the Principal Subjects are qualifications in their own right. They are acceptable as an alternative to A Level (or other Level 3 qualifications) for entry into higher education or employment. Each individual Principal Subject is graded separately on a scale of nine grades: Distinction 1, Distinction 2, Distinction 3, Merit 1, Merit 2, Merit 3, Pass 1, Pass 2, Pass 3.

Subjects can also be combined with two core components to meet the requirements for eligibility for the Cambridge International Level 3 Pre-U Diploma. More details about the Diploma requirements and the core components can be found in a separate Diploma syllabus. The results of the individual Principal Subjects are reported on a separate certificate to the Diploma result.

Classification code for UK Centres

In the UK, every syllabus is assigned to a national classification code that indicates the subject area to which it belongs. UK Centres should be aware that candidates who enter for more than one qualification with the same classification code will have only one grade (the highest) counted for the purpose of the School and College Performance Tables.

The classification code for this syllabus is **1010**.

Language

This syllabus and the associated assessment materials are currently available in English only.

Procedures and regulations

This syllabus complies with the *CIE Code of Practice* and *The Statutory Regulation of External Qualifications 2004*.

Further information about the administration of Cambridge Pre-U qualifications can be found in the *CIE Handbook for UK Centres* available from CIE Publications or by contacting **international@cie.org.uk**.

Spiritual, moral, ethical, social, legislative, economic and cultural issues

The syllabus provides a number of areas in which candidates may appreciate the moral, social, ethical, economic and cultural issues surrounding biotechnological industries, biological research and conservation both on a local and on a global scale. It is expected that candidates will gain a deeper appreciation and understanding of the molecular and life science workings of the world around them. There are no legislative issues in this syllabus.

Health and safety issues

The following health and safety issues feature in this syllabus:

- safe practice in laboratories
- issues associated with the impact of biotechnological industry and environmental research

Health and safety issues are covered in Appendix 1.

Environmental education and sustainable development

Aspects of environmental education and sustainable development are covered throughout the syllabus.

European and international dimension

There are opportunities in this syllabus to investigate local, national and international contributions to the subject field and to appreciate the global significance and impact of biology.

Avoidance of bias

CIE has taken great care in the preparation of this syllabus and assessment materials to avoid bias of any kind.

Key Skills

This syllabus provides opportunities for the development of the Key Skills of *Communication*, *Application of Number*, *Information Technology*, *Working with Others*, *Improving Own Learning and Performance* and *Problem Solving* at Level 3. However, the extent to which this evidence fulfils the Key Skills criteria at this level will be totally dependent on the style of teaching and learning adopted for each section.

The following table indicates where opportunities may exist for at least some coverage of the various Key Skills criteria at Level 3 for each section.

Section	Communication	Application of Number	IT	Working with Others	Improving own Learning and Performance	Problem Solving
1	✓	✓	✓	✓	✓	✓
2	✓		✓	✓	✓	✓
3	✓		✓	✓	✓	✓
4	✓		✓	✓	✓	✓
5	✓	✓	✓	✓	✓	✓

University of Cambridge International Examinations
1 Hills Road, Cambridge, CB1 2EU, United Kingdom
Tel: +44 1223 553554 Fax: +44 1223 553558
Email: international@cie.org.uk Website: www.cie.org.uk